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REGIONAL INVESTIGATIONS OF TECTONIC AND
IGNEOUS GEOLOGY IRAN, PAKISTAN, AND TURKEY

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Investigation 28410

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cooperation with Economic Programme, Central Treaty Organization
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16. Abstract

In cooperation with NASA and under the auspices of the Economic Programme of the Central Treaty Organization (CENTO), the governments of Iran, Pakistan and Turkey conducted investigations of applications of Landsat imagery to the analysis of tectonic and igneous geology in their respective countries.

Traces of faults not previously mapped and new understandings of segments already known were derived from the studies. The images were found useful also for refining boundaries of rock types already mapped and for extrapolating information on rock types in gross, from known areas to unknown areas. Included also is a report of practical application of Landsat imagery in petroleum exploration.

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PREFACE

The objective of the Regional Investigations has been to assess the applicability of Landsat imagery to studies of tectonic and igneous geology in Iran, Pakistan, and Turkey.

Landsat 2 images for selected areas of each country were analyzed by using visual methods. Black and white photographic prints and transparencies at 1:1,000,000 scale, and--to a limited extent--color composites and color additive displays produced on viewer screens were the formats in which the data were studied.

In each country's study, it was found that the Landsat data were helpful in detecting previously unmapped structural lineations and in understanding relationships among previously known segments of faults. The images were helpful also in refining boundaries of previously mapped outcropping formations and in extending knowledge of gross rock types from known areas to relatively unknown areas.

In Iran, a Landsat image was used in a very practical way to study the geologic setting of an anticline of interest for petroleum prospecting, and, on the discovery of an apparent line of faulting, to guide field work and the designation of a favored drilling locale.

The tectonic portion of the study was a project of the Working Group on Recent Tectonics and, therefore, included an interest in searching for evidence of recent earth movements. It was found that conclusive evidence of such movements could not be detected in the images and that data of much higher resolution and stereoscopic character would be required for such purposes. In addition, it is believed that the unique picturing by Landsat of fault and fracture traces is especially valuable for understanding the stress-systems and mechanics of deformation of continental plate margins. Tonal differences and terrain textures as depicted in the images permitted differentiation among some major classes of rocks of volcanic, igneous, sedimentary, and metamorphic domains. The presence of fault contacts among rocks of different types also aided in differentiation. Images in black and white were useful; projection in color was found to enhance their usefulness. The degree to which differentiation is possible was found to be limited by the relatively limited resolving power of the Landsat imaging system.

Country specific conclusions are as follows:

Iran

Known fault lines and lineations that might represent previously unknown fault traces were identified in the data for Iran. In general, the Landsat images contributed to more ready recognition and delineation of large-scale structural features than have more highly detailed, small-area study materials.

It was shown that principal stratigraphic and morphologic divisions could be recognized among volcanic rocks that crop out at the surface.

A practical application to ongoing geologic exploration for oil was demonstrated when the trend of a major lineament cutting a major anticlinal structure was discovered on Landsat imagery. In the field, the lineament was found to separate geologic formations that might be oil bearing from others which are not likely to be.

Pakistan

Known lines of faulting have been recognized and a previously unknown active fault system, the Quetta-Mustung-Surab, has been discovered in the Landsat images of Pakistan.

Rocks of an ophiolitic suite exposed in the Lasbela igneous complex have been differentiated; pre-existing maps of this area, where remoteness and rugged terrain make field work difficult, have been improved.

Turkey

A major line of faulting, the presence of which had been hypothesized, was found to be revealed by Landsat images. Two other lineations having lengths of 200 km are revealed and are deemed also to be the traces of faults; these will be investigated in the field.

INTRODUCTION

In response to announcements by the United States Government of opportunities to participate in the Landsat experiments, the Advisory Group on Mineral Development of the Central Treaty Organization proposed a project, Regional Investigations of Tectonic and Igneous Geology. This Advisory Group had been established in 1961 to accelerate the mapping, exploration, and utilization of mineral resources in Iran, Pakistan, and Turkey. In the ensuing years, symposia, training courses, seminars, cooperative stratigraphic and resource studies, and joint surveys along international boundaries, had been conducted, with aid from consultants from the United Kingdom and the United States.

The proposed project would be carried out as parts of newly instituted studies of tectonic activity and of igneous rocks in the principal tectonic zones of the CENTO region. Teams made up of members of the Geological Surveys of each country were designated to perform the studies in their own countries. In addition, under the auspices of CENTO and with the cooperation of the Ministry for Overseas Development of the United Kingdom, the U.S. Agency for International Development (USAID), and the U.S. Geological Survey, a series of workshops on applications of remote sensing was held at Ankara, Turkey, 1971; at Tehran, Iran, 1972; at Lahore, Pakistan, 1975; and at Istanbul, Turkey, 1976.

In each country, organizational units have been formed to promote the use of Landsat data in support of routine geological analysis and mapping programs.

INVESTIGATIONS IN IRAN BY THE GEOLOGICAL SURVEY OF IRAN

The activities of the Geological Survey of Iran in the Regional Investigation of Tectonic and Igneous Geology included: (1) the subjective study of two major fault systems, the Doruneh and the Great Kavir (or Kuh Banan) to develop an understanding of the values of Landsat images for such work; (2) an objective study of two Landsat scene areas, Baft and Tehran, to determine the degree of usefulness of discovering tectonic features; (3) an igneous area, the Natanz-Nain-Surk region, to evaluate the usefulness of the Landsat images for mapping of igneous terranes.

In addition, the results of a study in petroleum exploration by the National Iranian Oil Company are reported herein.

In support of the Regional project, the Geological Survey of Iran established a Remote Sensing Section, obtained two color-additive viewers (I^2S) and conducted a training course on application of remote sensing in geology from April 11 to 30, 1976. At the invitation of the Government of Iran, the Governments of Pakistan and Turkey sent members of their Geological Surveys' staffs who were cooperating in the Regional Investigations to attend the course. Expenses of travel and per diem for these were borne by the CENTO.

The National Aeronautical and Space Administration (NASA) supplied Landsat-2 imagery in positive prints and transparencies at 1:1,000,000 scale and in positive and negative transparencies at 1:3,369,000 scale.

A map index to the data (fig. 1) was prepared and a system for archiving and control of the data was established. Both the Remote Sensing Section and the Tectonic and Seismotectonic Section of the Geological Survey of Iran took part in the project.

Investigation of tectonic geology

The Great Kavir, or Doruneh, fault (fig. 2) is one of the most extensive and prominent faults in Iran, being evident both in regions of hard rocks and in alluvial fans and sandy deserts. Wellman (1966) and Gansser (1969) considered it to be active. Wellman, who first mapped the fault, did so on the basis of study of aerial photomosaics. He observed sinistral displacement of about 200 meters of four small streams, closely spaced in one locality, and of 75 m at a second. The trace of the fault extends some 750 km commencing south and a little west of Nain, in the southeast of the northwest quarter of Iran, trends northward for 100 km, then northeastward across the Great Kavir to the vicinity of Doruneh, from whence it bends eastward, passing north of Kashmar before bending southward to die out north of Khaf.

The second tectonic area chosen to test the visibility in Landsat imagery of known fault features is that of the Kuh Banan fault, in southeastern Iran (fig. 3). The fault trace commences near Bahabad and trends southeastward, passing just east of Kerman and terminating at the trace of the Gowk fault. The trace of the fault is most readily perceived at its northern end where it involves early Cambrian formations that are thrust over younger Paleozoic and Triassic rocks. It is much less evident in areas of Pliocene-Pleistocene gravel and conglomerate and is not evident in the southern part of the northern third of its extent in areas of Quaternary fanglomerate. In its southern two thirds, the trace of the fault is marked by the west-facing front of Jurassic and Cretaceous rocks. In the absence of evidence of disturbance of the Quaternary fanglomerate, it is surmised that there has been no movement in recent time along the northern segment of the Kuh Banan fault.

Comparison of the Landsat images of the regions of the Great Kavir (Doruneh) fault and the Kuh Banan fault with previous records, including aerial photography, revealed that the Landsat images provide a clearer, simpler, more direct and efficient means of recognizing and mapping these large-scale features than the pre-existing observation techniques did. It was not possible to determine from the imagery per se whether or not the faults are still active. It might be assumed, however, that images from repeated observations would reveal evidence of major displacements that were consequences of recurrent activity along the faults.

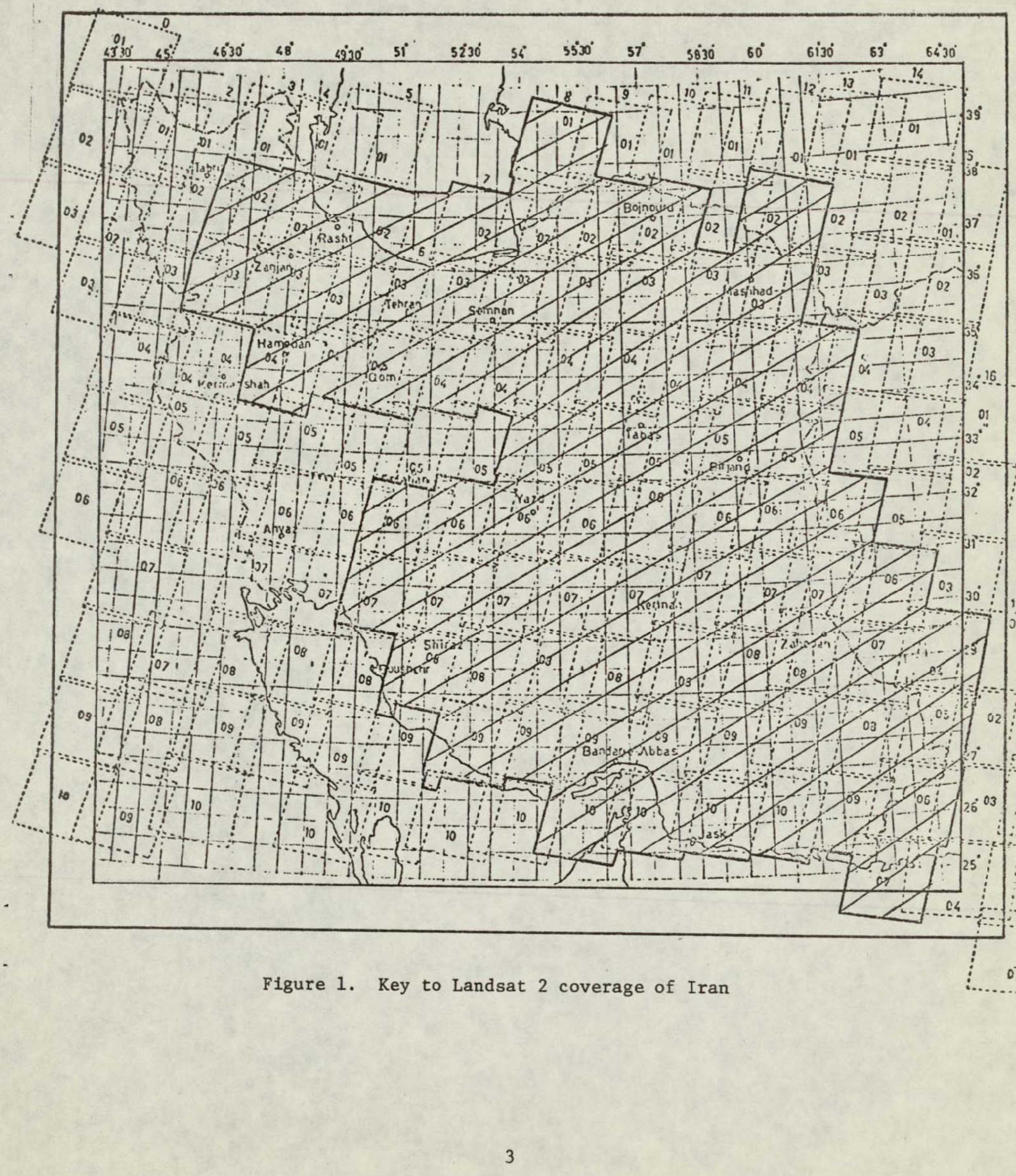

Figure 1. Key to Landsat 2 coverage of Iran

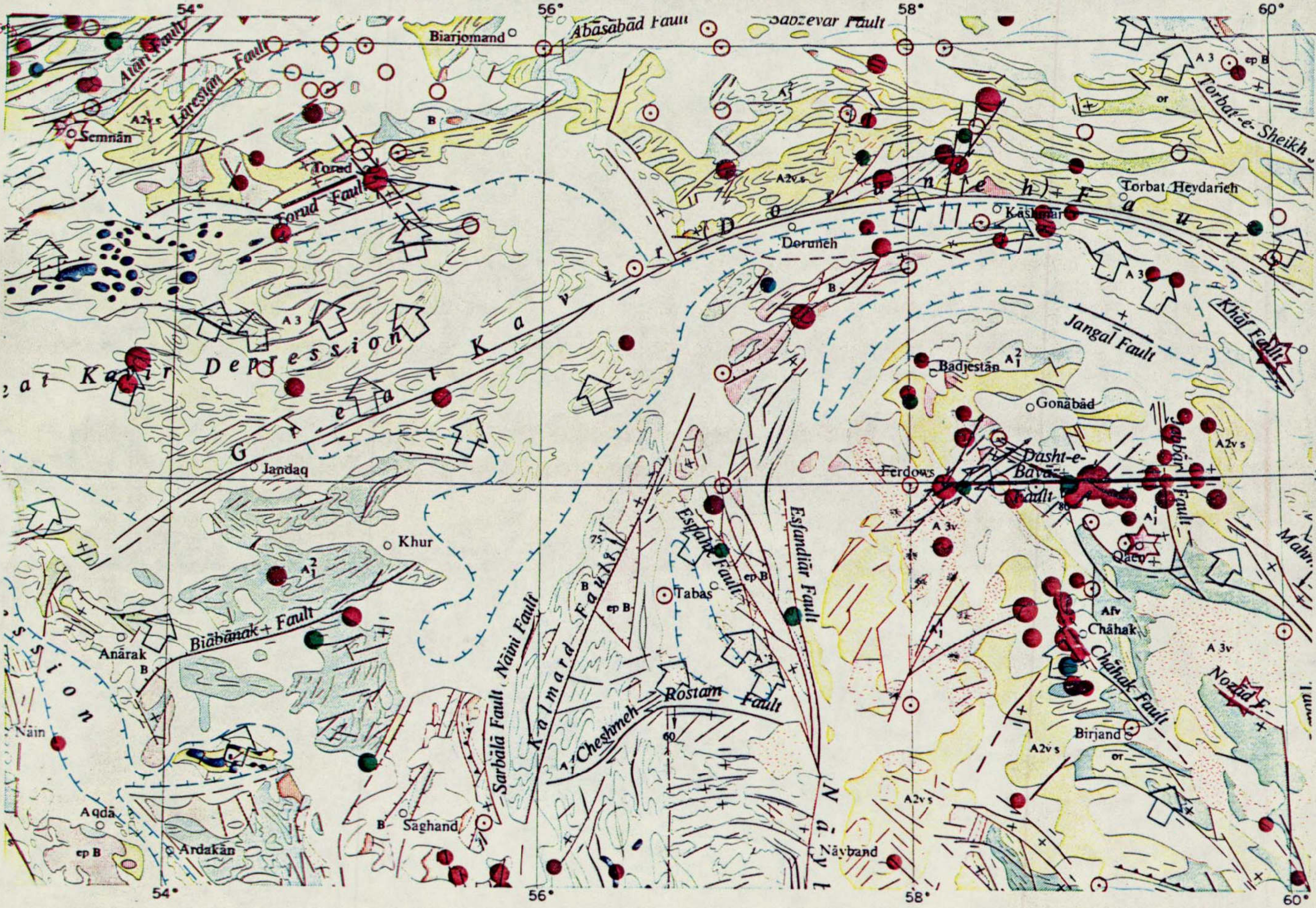

Figure 2. Trace of the Great Kavir (Doruneh) Fault

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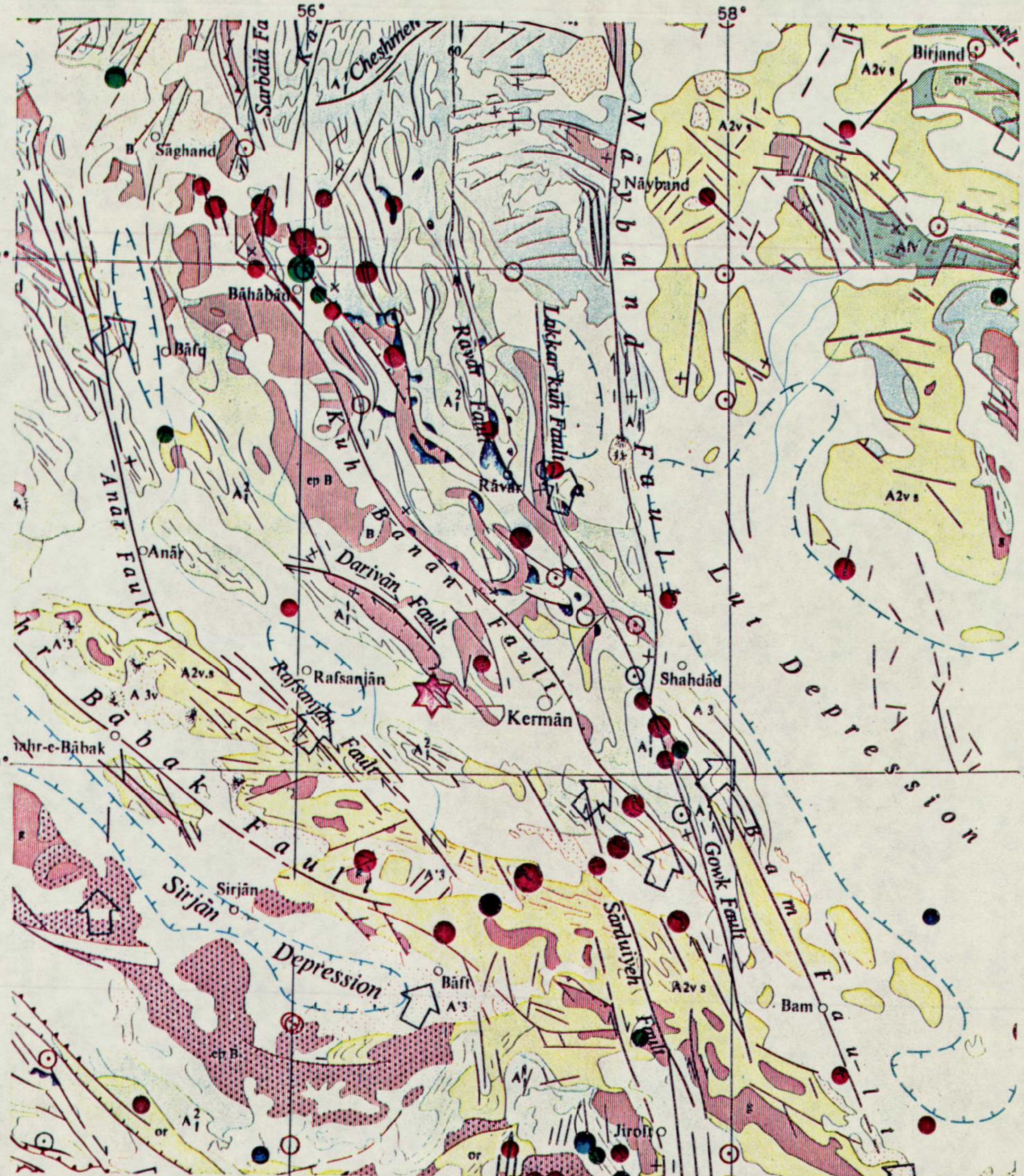

Figure 3. Trace of the Kuh Banan Fault

Landsat image number 2017-06060-7 of the Baft area (fig. 4) in southeastern Iran and image number 2130-06322-7 of the Tehran area were studied to determine the values of such data for the analysis of tectonic conditions.

Six lineaments were detected in the image of the Baft area (fig. 5). The first (no. 1) is the trace of the main Zagros reverse fault (Berberian) which separates the Zagros fold belt of southwestern Iran from the central Iranian zone, and along which Precambrian and Paleozoic metamorphic rocks have been thrust over the younger rocks of the Zagros fold belt.

The second lineament shown on figure 5 is directly from the Landsat image in which it appears to be a surface expressions of the northern limit of a downthrown block that formed the mud-covered Dolatabad depression.

The third lineament, also from the Landsat image, crosses the mudded surface of the Sirjan depression and is presumed to be the trace of a downthrown southwestern block. Both the second and third lineaments must be checked in the field in order to confirm their geologic nature and our hypotheses.

The fourth lineament is the trace of the Khabr fault, a high-angle reverse fault along which previously completed studies have shown Paleozoic and Precambrian metamorphic rocks to be up against Mesozoic formations.

Lineaments 5 and 6 are the traces of the Gushk and the Deh Sard faults. These also had been mapped by work completed prior to the Landsat study and are depicted clearly in the Landsat image.

Figures 6 and 7 illustrate five lineaments seen in the Landsat image of the Tehran area; 1 and 2 are the traces of the North Tehran and the North Qazvin (Annels, 1975) faults, both of which had been mapped previously.

Lineament number 3 is from the Landsat image and appears to mark the north limit of the Eshtehard-south Tehran area volcanics. Number 4 is the trace of the Kushk-e-Nosrat fault, which in large part makes a northward-facing front of Eocene volcanics against a Quaternary depression, but which also involves the volcanics themselves. Number 5 is a lineament, not mapped heretofore, that is transverse to the general trends and cuts both Quaternary deposits and Eocene volcanics.

Investigation of igneous geology

The Natanz-Nain-Surk region of central-eastern Iran (fig. 8) was selected for study of the applicability of Landsat images to differentiation of rock types for mapping purposes. It was found that distinctions could be made only among principal divisions based upon gross morphologic and stratigraphic features.

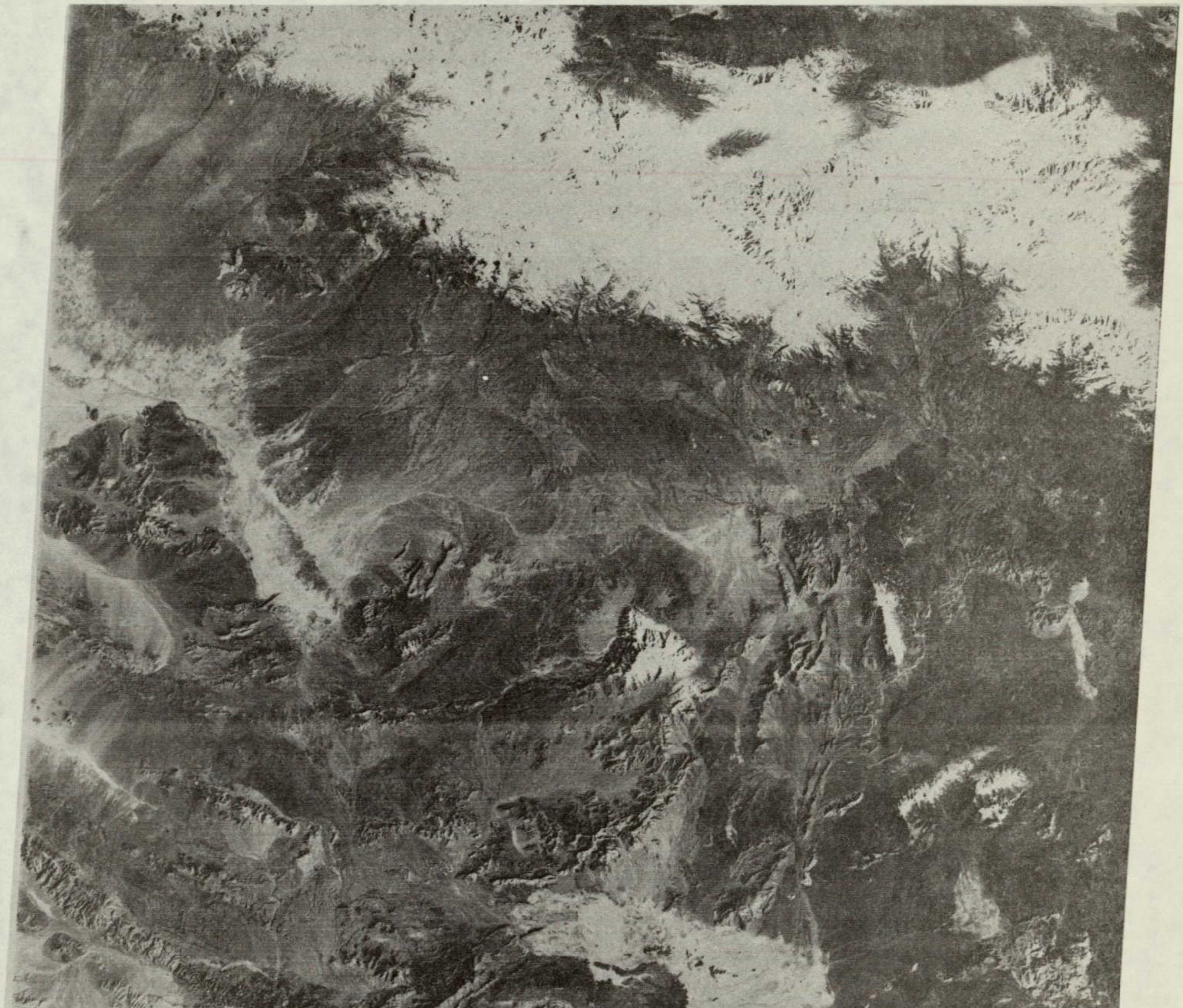

Figure 4. Landsat image of the Baft area, Iran

BAFT AREA

Figure 5. Lineaments of the Baft Area, Iran

EXPLANATION

Qt	Quaternary i.g.
N	Mio-Pliocene (Neogene i.g.)
N	Conglomerate
M	Miocene i.g.
OM	Oligo-Miocene, including Oligocene red beds
E	Eocene
E	Volcanic Eocene i.g. (Green beds of Alborz)
Eo	Paleogene of SE Iran (may include K_2)
MZ	Mesozoic i.g. (mainly limestone)
K	Cretaceous i.g.
K_2	Upper Cretaceous (Turon - Senon)
K_2	Coloured Melange
MZ	Siliceous facies of Jurassic - Cretaceous (Zagros)
J_2	Upper Jurassic
PA	Paleozoic i.g.
Mt	Metamorphics i.g.
	Schists and Slates
	Marbles
	acid
	intermediate igneous rocks
	basic
	Diapiric Uplifts (mainly salt domes)
	Extrusive
	Intrusive

1:1000000

①	Zagros Fault
②	Lineament from Landsat
③	Lineament from Landsat
④	Khabr Fault
⑤	Gushk Fault
⑥	Deh Sard Fault

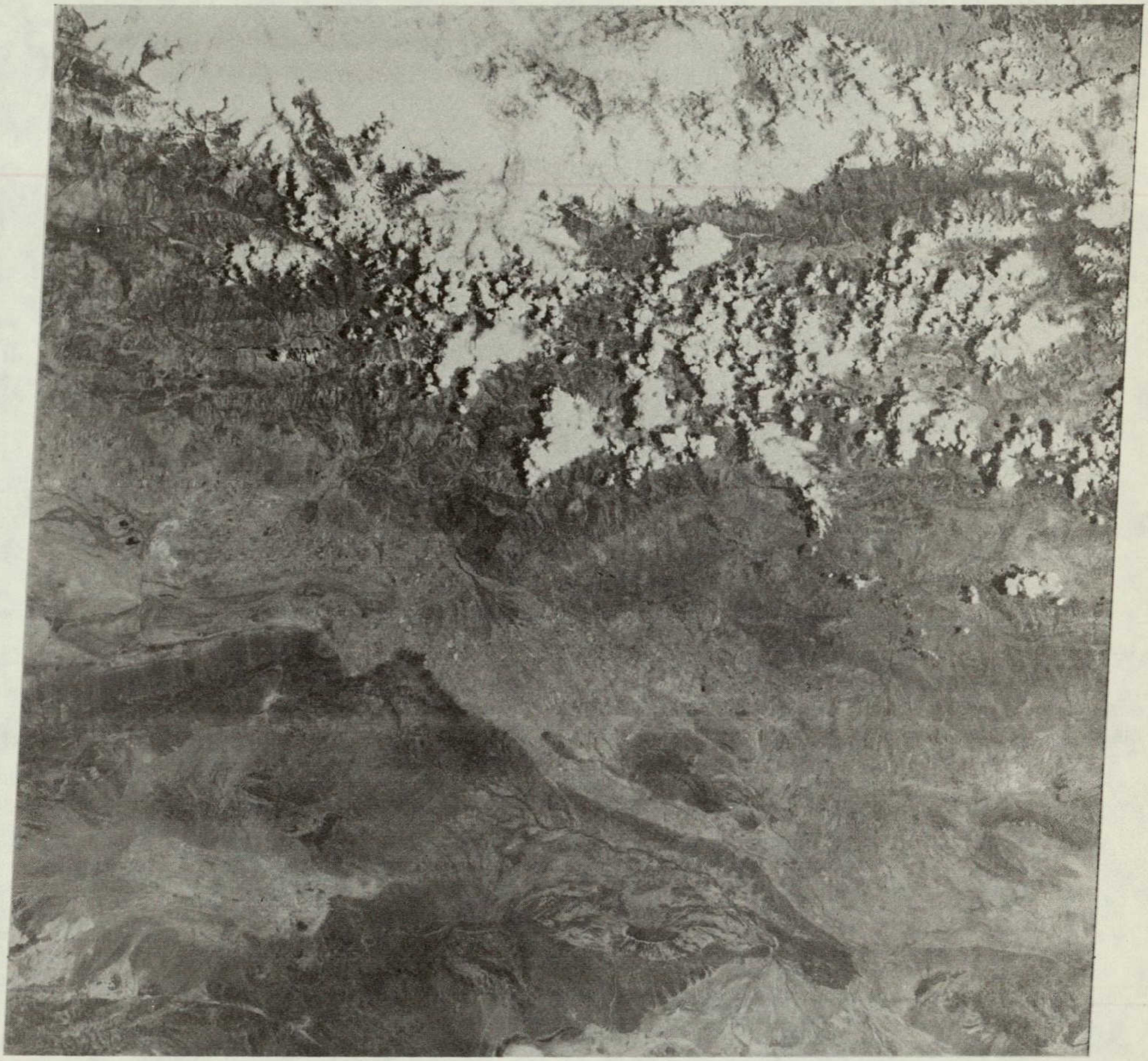

Figure 6. Landsat image of the Tehran area, Iran.

Rocks of this region range in age from Paleozoic to Quaternary and in character from magmatic through sedimentary and metamorphic. The region can be divided on the basis of major structural and petrologic characteristics into four zones. At the northwestern end, Paleozoic to Cretaceous sedimentary rocks predominate west of the Zephreh fault. East of the Zephreh fault and, roughly, between Ardestan and Nain, volcanics are predominant, and are comprised of the widest possible range of magmatic types. They have been emplaced as plutons, pyroclasts, and flows at periods between Eocene and the Quaternary. Farther southeastward, the rocks of a third zone are Paleozoic metamorphics and Cretaceous volcanics and sedimentary beds that are, in places, overlain by Paleozoic calcareous strata. The southernmost, fourth, zone of this region of study is occupied by a complex of grabens in which occur members of a pre-Cretaceous ophiolitic series, Upper Cretaceous marine sedimentary rocks, and a colored melange resulting from post-Late Cretaceous tectonic mixing of all.

APPLICATION IN PETROLEUM PROSPECTING

New geologic information by the National Iranian Oil Company[1/] having an important bearing upon the location of a petroleum exploration test was derived from analysis of Landsat imagery of the Fars region of southern Iran (fig. 9). The Kuh-e-Tudej anticline, which is situated southwest of Neyriz and near the northeastern edge of the Zagros fold belt, had long been considered to be a most favorable structure for testing possible reservoir formations between the Sarvak of Cretaceous age and the Kuff of Permian age (fig. 10). The Tarbur Limestone (Upper Cretaceous) was known to be exposed in the core of the anticline, but field work had led to the discovery, also, of a small outcrop of radiolarites below the Tarbur at a locality just east of the eastern end of the structure. Consequently, a critical question in regard to location for a test centered on the character and distribution of rocks involved in the structure, because it lies in an area between the region of folded Zagros structures and producing formations to the southwest, and the extremely disturbed region of thrusts to the northeast in which occur the pelagic radiolarites that would be unfavorable for oil prospecting.

Examination of Landsat image 1149-06291-6 (fig. 11) at a scale of 1:1,000,000 revealed the presence of a lineament, not previously mapped, trending N.15°W. across the broad, eastern end of the Kuh-e-Tudej structure. Additional field examination led to the discovery of additional exposures of the radiolarite to the east of the lineament, but none to the west of it, and to a conclusion that the lineament marks the eastern margin of a Late Cretaceous continental platform on which shallow marine marl and argillaceous

1/ Agah, Siamak, 1976, An application of Landsat imagery in petroleum prospecting in Iran, Proceedings, CENTO Workshop on Applications of Remote Sensing Data and Methods, October 5-12, 1976, Istanbul, Turkey: in preparation.

TEHRAN AREA

Figure 7. Lineaments of the Tehran Area.

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EXPLANATION

Q	Quaternary i.g.
QP	Plio - Pleistocene, Fresh water Limestone
N	Mio-Pliocene Conglomerate
M	Miocene i.g.
Mc	Caspian Miocene
M_2	Upper Part — Upper Red Formation (Fars)
M_1	Lower Part — Upper Red Formation (Fars)
OM	Oligo - Miocene including oligocene red beds
E	Volcanic Eocene
Mz	Mesozoic i.g. (mainly Limestone)
K	Cretaceous i.g.
K_2	Upper Cretaceous(Turon-Senon)
K_1	Lower and Middle Cretaceous
J_2	Upper Jurassic limestone (may in clude K_1)
J_1	Lower to Middle Jurassic
Tr	Triassic
PA	Paleozoic i.g.
PC	Permian - Carboniferous
D	Devonian (Partly Old Red type)
€	Pre - Devonian Paleozoic
Mt	Metamorphic i.g.
	intermediate — igneous rocks
	basic — igneous rocks
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①	North Tehran Fault (Tchalenko et al, 1974)
②	North Qazvin Fault (Annells et al, 1975)
③	Lineament from Landsat
④	Previously mapped fault
⑤	Lineament from Landsat

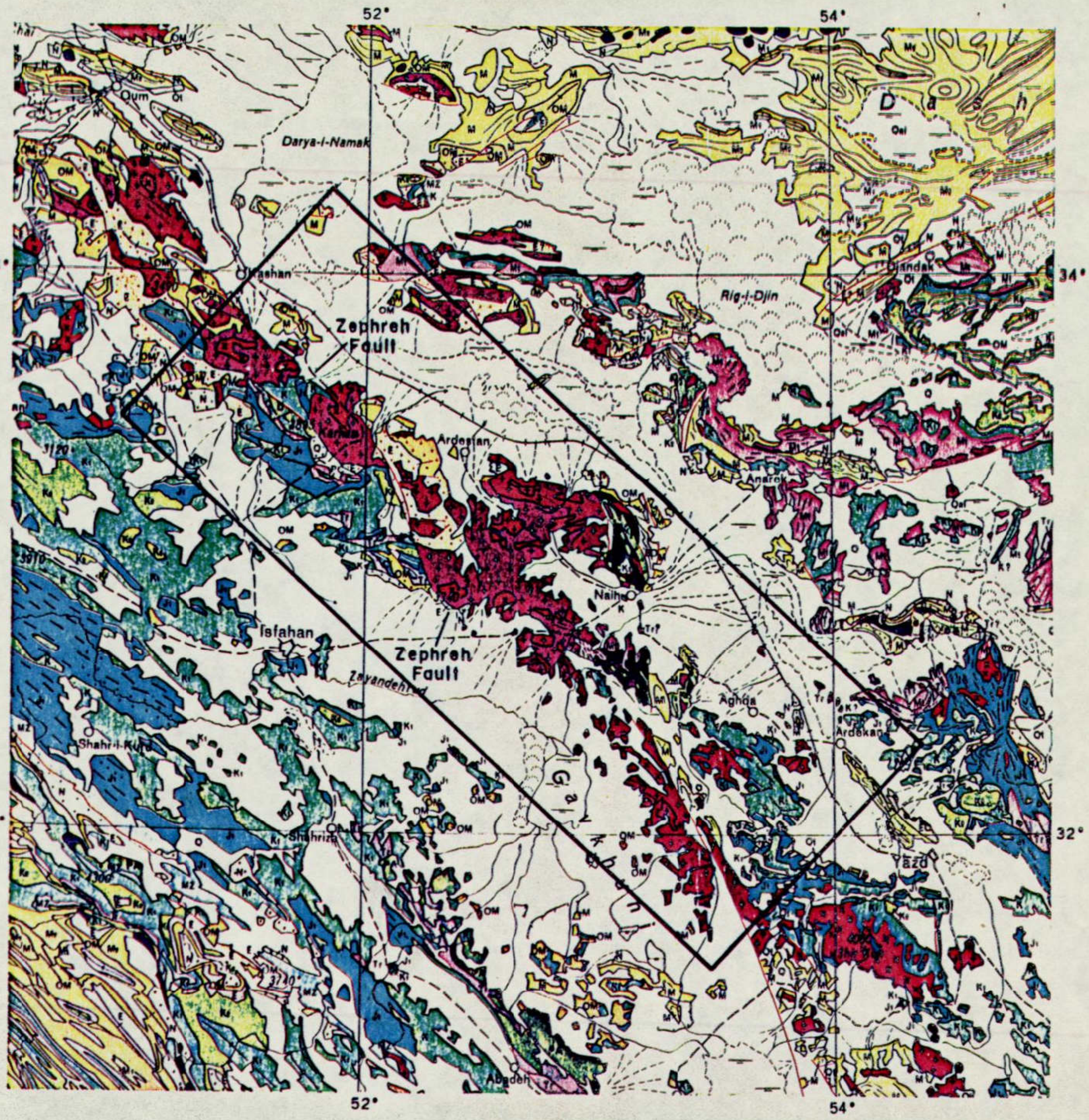

Figure 8. Natanz-Nain-Surk region of Tertiary volcanics, Iran

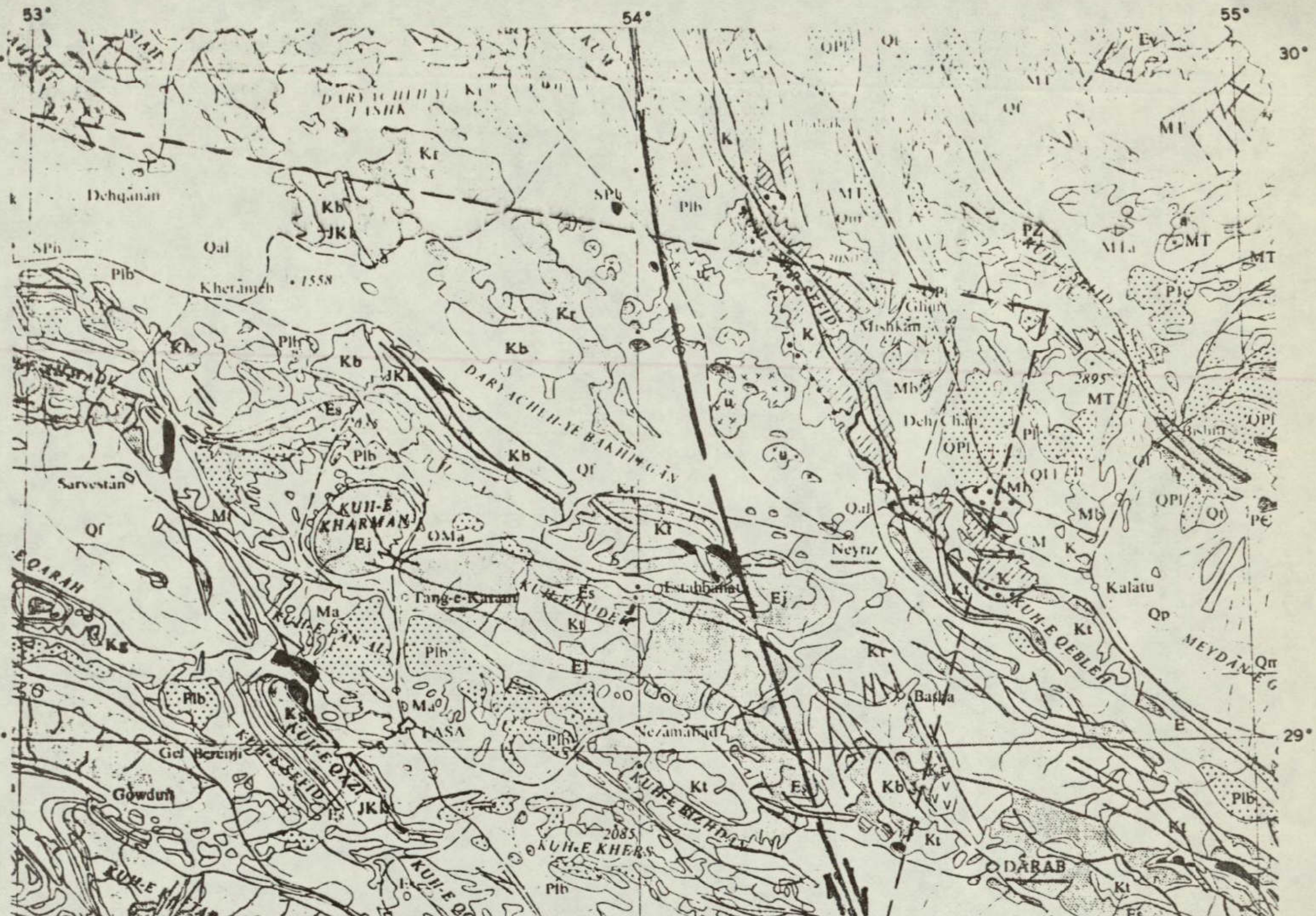

Figure 9. Part of geological map of Iran showing the Fars area and the position of a northwest-trending strong lineament discovered on Landsat image 1149-06291.

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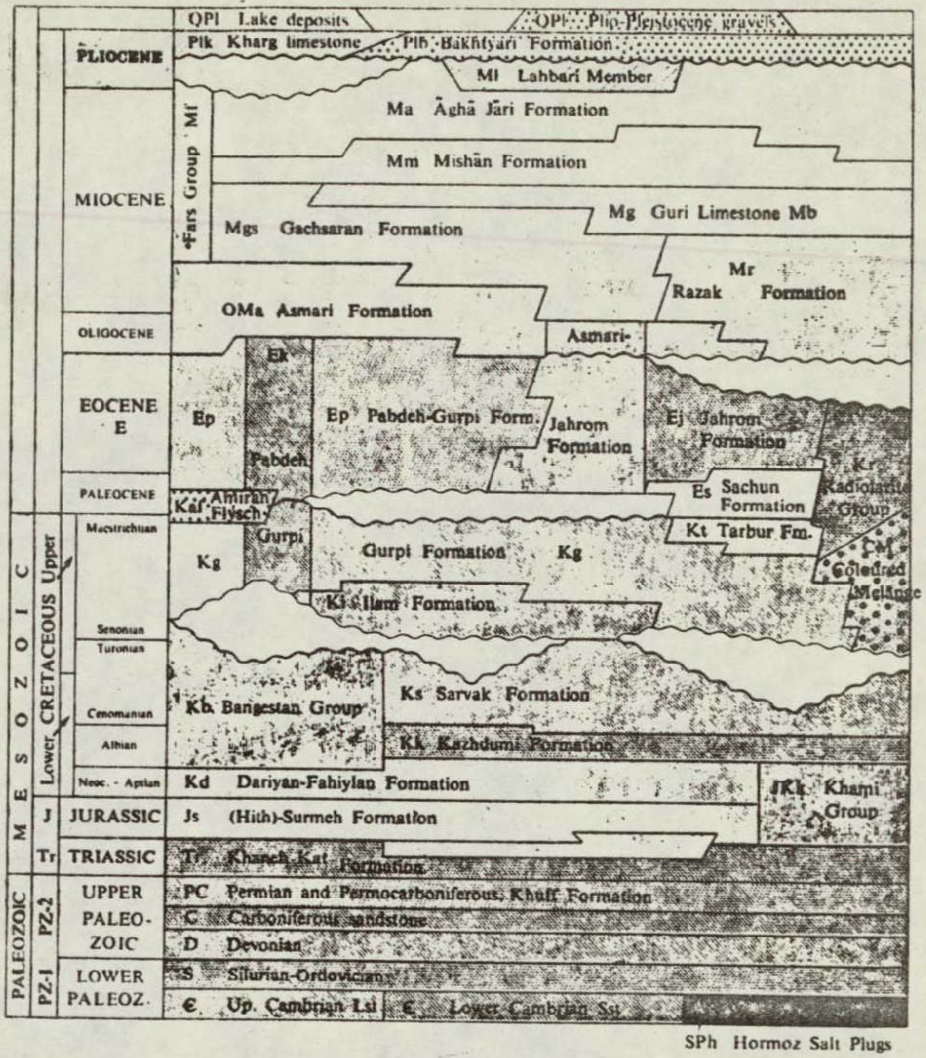

Figure 10. Chart depicting sedimentary formations of southwestern Iran.

Agah

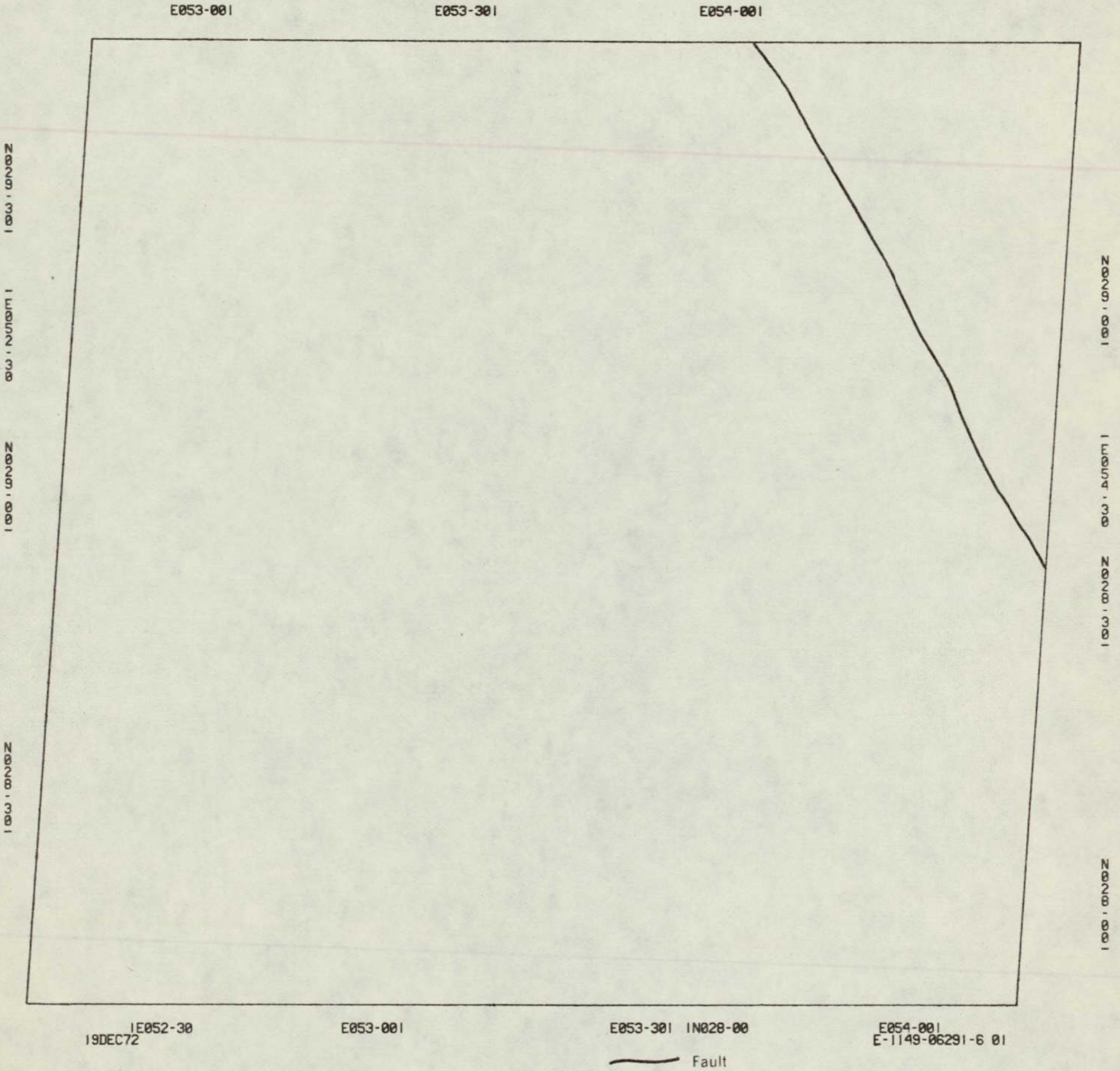

Figure 11. Overlay.

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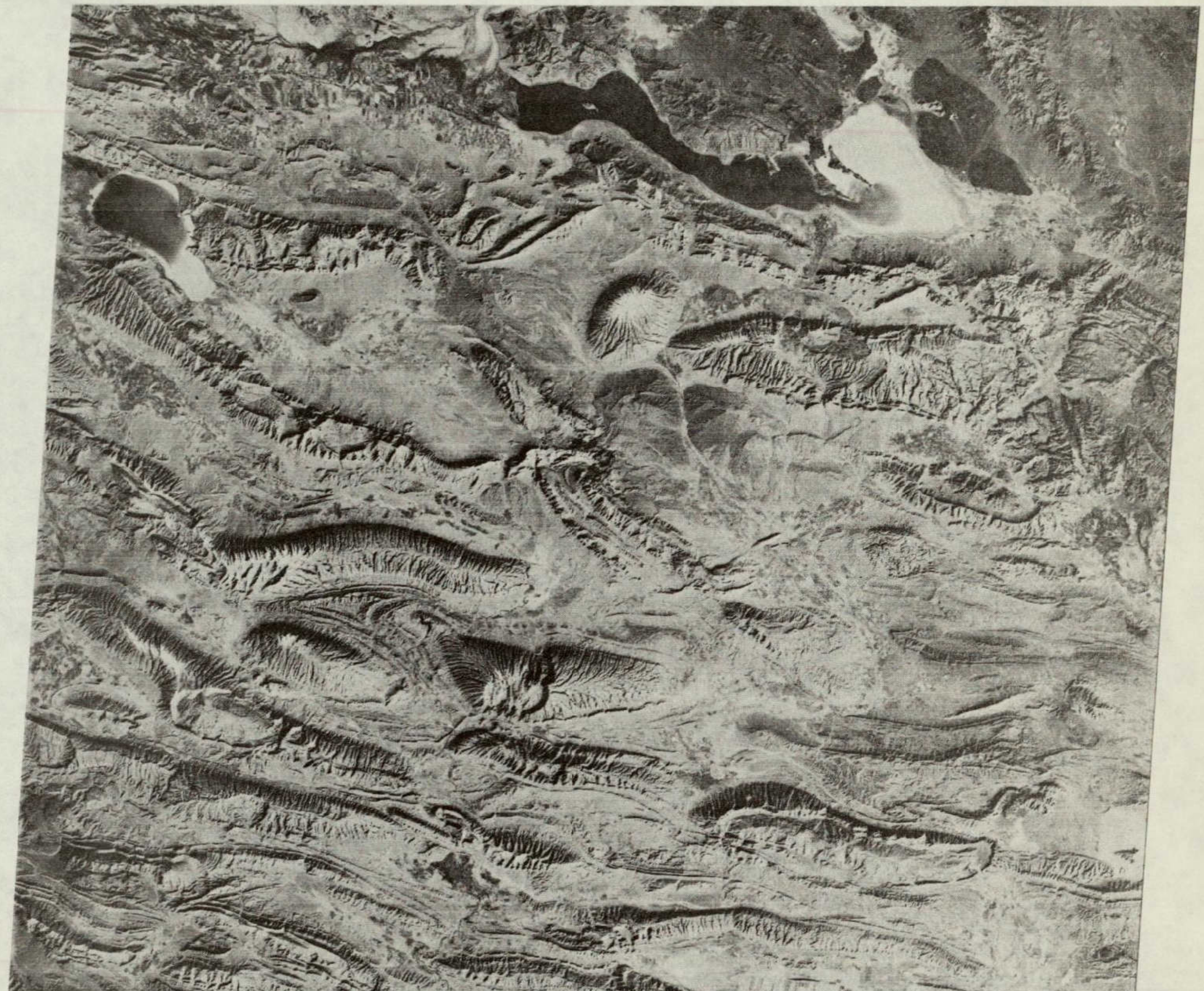

Figure 11. Landsat image of the Fars region.

limestone accumulated under conditions favorable to petroleum and to reservoir development, and east of which radiolarites were deposited on the continental slope and the abyssal plain in environments that are not generally favorable. Thus, the Tudej anticline should be tested west of the lineament observed in the Landsat image.

INVESTIGATIONS IN PAKISTAN BY THE GEOLOGICAL SURVEY OF PAKISTAN

Abstract

The visual interpretation of Landsat data resulted in accurate delineation of the Chaman-Nushki and the Ornach-Nal capable fault systems. A younger capable fault named/designated as the Quetta-Mustung-Surab fault system was detected, delineated, and interpreted. The Chaman-Nushki and Ornach-Nal faults are inferred to be the remnants of a boundary-transform left-lateral fault. Their continuity was disrupted due to differential lateral movements that offset the southern segment towards the east. This tectonism resulted in the development of the Quetta-Mustung-Surab fault system. The younger faults are seismically active and extend to depths of 100 km.

Analysis of Landsat images shows that different layers of an ophiolitic suite exposed in the Lasbela igneous complex can be delineated, and that the lowermost layer consisting of ultramafic rocks is exposed in the north, whereas an upper layer consisting of pillow lava is exposed in the south.

Spectral reflectance variations as depicted by the images were used to differentiate among different types of igneous rocks.

Introduction

Under an agreement between NASA and CENTO, remote-sensing data acquired by ERTS-B (Landsat-2 or Landsat B) were studied visually by Pakistani experts in the fields of intrusive and volcanic rocks and for recent tectonics . Four frames of Landsat imagery along one orbital strip over Pakistan through coordinates 31° N. and 67° E., were interpreted for tectonic studies, and three frames were interpreted for igneous geology studies. The Landsat-2 data supplied by NASA was excellent in quality. False color composites at 1:500,000 and 1:250,000 scale would have been useful for more detailed interpretation.

Techniques

Visual interpretation of Landsat data was done on three formats using different techniques. The following frames (MSS bands 4, 5, 6, 7) were viewed for recent tectonic studies:

Identification No.	*Frame No.	Date	Format and Scale
81103053235	F07	Nov. 3, 1972	Positive 1:3,369,000 transparencies.
82027052105	F07	Feb. 18, 1975	Black & white print. 1:1,000,000
82117052035	F07	May 19, 1975	Positive 1:1,000,000 transparencies.
82028052535	G02	Feb. 19, 1975	Black & white prints. 1:1,000,000
82136052525	G02	June 7, 1975	Positive 1:1,000,000 transparencies.
82028052605	G03	Feb. 19, 1975	Black & white prints. 1:1,000,000
82136052545	G03	June 7, 1975	Positive 1:1,000,000 transparencies.
82244052455	G04	Sep. 23, 1975	Positive 1:3,369,000 transparencies.
82028052625	G04	Feb. 19, 1975	Black & white transparencies. 1:1,000,000
82136052615	G04	June 7, 1975	Positive 1:1,000,000 transparencies.
81176053735	G05	Jan. 15, 1973	Positive 1:3,369,000 transparencies.
82028052655	G05	Feb. 19, 1975	Black & white transparencies. 1:1,000,000
82136052635	G05	June 7, 1975	Positive 1:1,000,000 transparencies.

*(For reference, see index map, fig. 12).

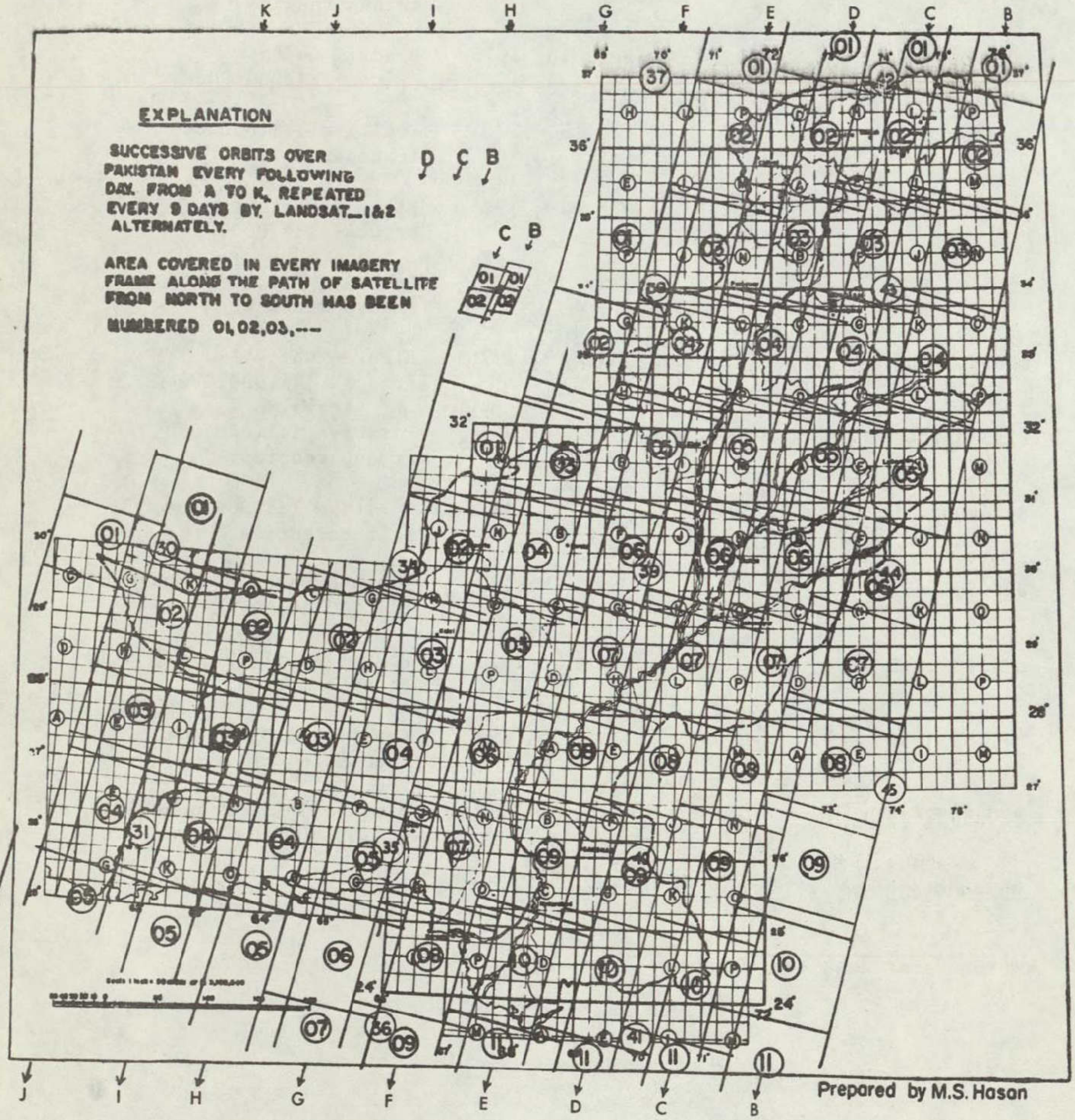

Figure 12. Index map to Landsat coverage of Pakistan.

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Positive transparencies at 1:3,369,000 scale were studied on a Mini Addcol Viewer using different color filters for different bands. The scenes were studied in natural color and also in false color. The linear features were enhanced in false color, in which blue color was used for band 4, green for band 5, and red for band 7. Band 6 was not used as it did not help in enhancement.

Black and white prints at 1:1,000,000 scale were studied under reflected light with the help of a magnifying glass. Owing to nonavailability of unsensitized transparent film in the country, overlays could not be laid on black and white prints for tracing the details. The translucent overlays masked the details.

Positive transparencies at 1:1,000,000 scale were used for the preparation of color composites by the diazo process. Yellow film was used for band 4, red for band 5, and blue for band 7. These color composites were studied on a light table with the help of a magnifying glass. The translucent overlays laid on these color transparencies did not mask the details to the extent that they had masked details of the black and white prints, and the tracing of lineations was facilitated. Linear features in every frame were traced on separate overlays. These overlays were mosaicked into a map and superimposed on a 1:1,000,000 scale base map. Corrections were made in the coast line as it did not match the old base map. The inland cultural features shown on the base map did not fit accurately with those on imagery. No attempt was made to revise the cultural features shown on the old map.

For studies in igneous geology, the following frames (bands 4, 5, 6, and 7) and different format were interpreted:-

Identification No.	Ref. No.	Date	Format	Scale
8110305325	F07	Nov. 3, 1972	Positive transparency	1:3,369,000
82027052105	F07	Feb. 18, 1975	Black & white prints	1:1,000,000
82117052035	F07	May 19, 1975	Positive transparencies	1:1,000,000
82136052455	G01	June 7, 1975	Positive transparencies	1:1,000,000
82028052535	G02	Feb. 19, 1975	Black & white prints	1:1,000,000

Identification No.	Ref. No.	Date	Format	Scale
82136052525	G02	June 7, 1975	Positive transparencies	1:1,000,000
82136052651	G04	June 7, 1975	Positive transparencies	1:3,369,000
82028052625	G04	Feb. 19, 1975	Black & white prints	1:1,000,000
82136052651	G04	June 7, 1975	Positive transparencies	1:1,000,000

Positive transparencies at 1:3,369,000 scale in bands 4, 5, 6, and 7 were studied on a Mini Addcol Viewer. For enhancing the contacts between sedimentary rocks and igneous rocks, and for differentiation among ultramafic, mafic and silicic igneous rocks, best results were achieved by adding a small amount of red color in band 4, full green color in band 5, and full blue color in band 7. This combination of colors obscured the vegetation details and also masked the cultural features.

Black and white prints at 1:1,000,000 scale were studied for differentiating among rock types. Band 5 offered the maximum contrast for such delineation.

False color composites were prepared with the help of positive transparencies at 1:1,000,000 scale using the diazo process and yellow film for band 4, red for band 5 and blue for band 7. Translucent overlays were laid on these false-color transparencies on a light table and the elements related to igneous rocks were delineated and plotted by use of a magnifying glass. The results of the diazo analysis were simultaneously checked against images of the some date projected on a Mini Addcol Viewer and against black and white prints of different dates. The overlays prepared were mosaicked into a map and superimposed on a base map at 1:1,000,000 scale, and a final map was prepared. The results achieved in the fields of tectonics and igneous geology are discussed below:

Tectonic studies

In the tectonic studies, elements that are related to present seismic activity in parts of Baluchistan, Pakistan, were delineated. Landsat imagery proved to be useful in delineating the traces of capable faults and their relationships. The synoptic view and the differentiation in the registration of details in different spectral bands due to moisture and vegetation effects were quite helpful in extracting the information along those segments of capable faults where they cut Recent alluvium.

The linear features found in the alluvium are at present occupied by small streams, have favored the growth of vegetation, or have slightly raised ground on one side.

The fault traces delineated are shown in figure 13. Two categories of faults were distinguished. These are inactive faults and capable faults. The inactive faults have been mapped but are not discussed in this report as to do so would involve a discussion beyond the scope of the present report. Among the capable faults, the traces of two known faults, namely the Chaman-Nushki and the Ornach-Nal faults, were delineated. An active fault system which was not known previously was detected and its trace was delineated on the Landsat imagery. The newly detected feature has been named the Quetta-Mustung-Surab fault system. All three fault systems are described below:

Chaman-Nushki fault system

The trace of the Chaman-Nushki fault was delineated for a distance of 330 km starting from a location east of Chaman, where it enters into Pakistan from Afghanistan, southward to a location northwest of the village of Besima. Previously the trace had been mapped for 288 km (180 miles). With the help of Landsat, an extension of the trace for 42 km was delineated. The fault trace has a north-northeast trend and appears distinctly on satellite imagery throughout this length noted. The trace is not clear farther south than Besima village. Streams offset in a left-lateral pattern could be noted and the trace is also distinct in Recent and sub-Recent deposits. The fault is concave toward the northwest north of Spinatiza village, and concave toward the southeast to the south of it.

The fault trace is known to extend farther north into Afghanistan for a distance of about 500-600 km to a location near Charikar village (Farah, 1976).

Most important structural intersections along the fault that have been detected for the first time with the help of landsat imagery are to the north and south of Spinatiza village. The seismic records over the past 70 years show that the northern segment from Chaman to Nushki is seismically more active than the southern segment. During an 1892 earthquake, (Griesbbach, 1893) the seismic activity was centered around the old town of Chaman where cracks and fissures developed. During the October 1975 earthquake (Farah, 1975) cracks and fissures developed in the vicinity of Spinatiza village only. The restricted movements along the Chaman segment in 1893 and subsequently along Spinatiza in 1975 are attributed to events at these structural intersections.

Ornach-Nal fault

The trace of the Ornach-Nal fault was delineated for 330 km, starting from the sea coast and proceeding northward to a location to the north of

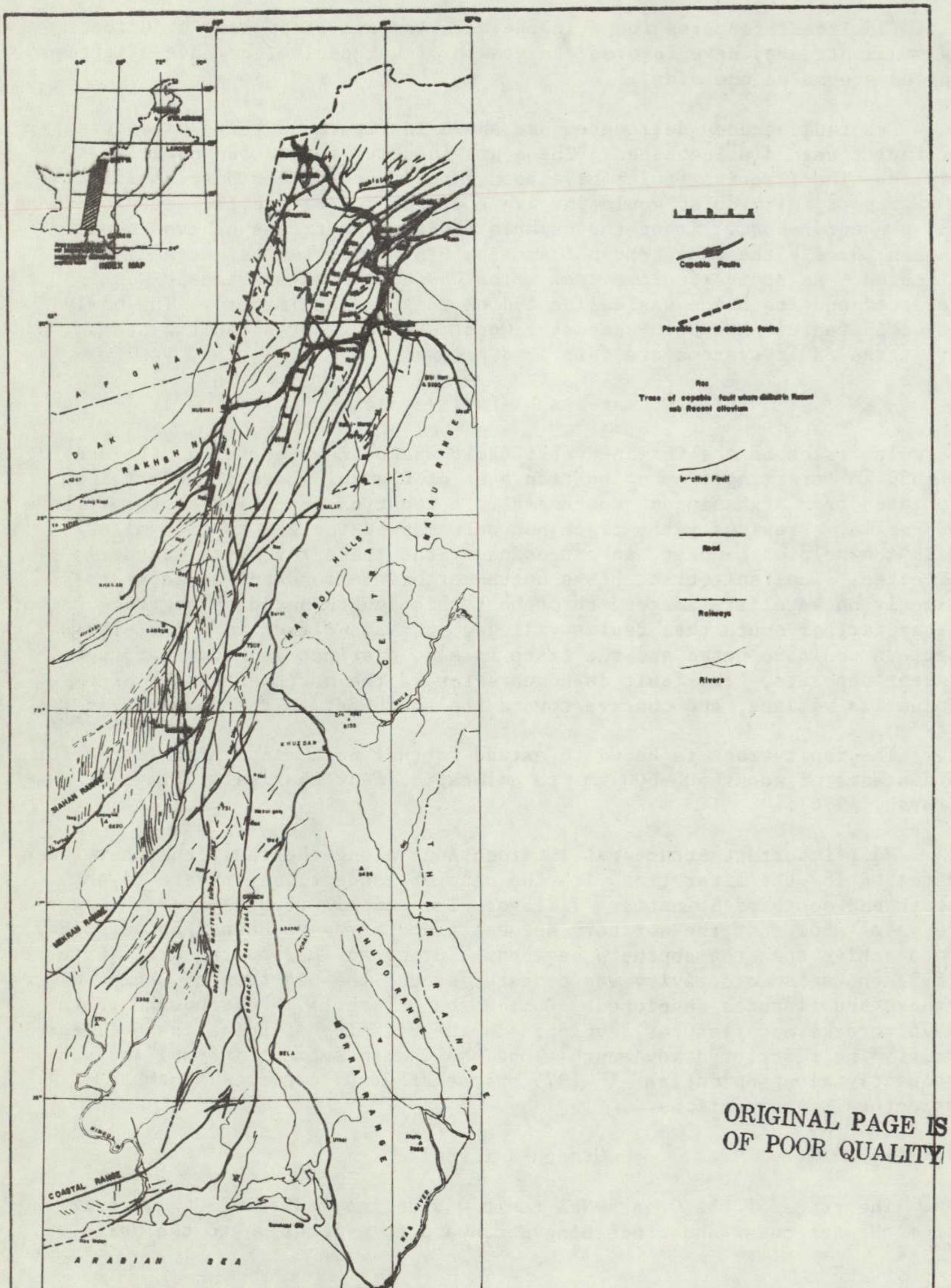

Figure 13. Map showing capable faults of part of Baluchistan, Pakistan.

and Farah (1975) described this fault to be 200 km long, and to have vertical and sinistral movements. It cuts Recent alluvium. They believe it to have been generated during the Eocene. Abrupt termination of strike on the two sides of the fault at 27°07' N., 66°07' E., was noted by Auden. It has been mentioned in the Reconnaissance Geology of Part of West Pakistan (1960) that the Ornach-Nal fault is a regional transcurrent fault, traceable for 100 miles and that the stratigraphic separation is several thousand feet, with the west side moving up relative to the east. The structure on either side of the fault differs in both kind and scale. This is possibly younger than the fault but is evidently consequent to principal stresses in the same direction. It is believed that the Ornach-Nal fault has a pre-orogenic beginning. Contemporaneous strata on either side of the fault are of great lithological contrast, even though closely adjacent. Two recent movements mentioned by Kazmi (1974) occurred on October 12, 1973, and June 8, 1974, at 25.5° N., 66.7° E., and had magnitudes of 4 and epicenter at 33 km depth in Sonmiani Bay. These earthquakes were probably caused by tectonic activity associated with the southern segment of the Ornach-Nal fault.

Quetta-Mustung-Surab fault system

A most important result of interpretation of the Landsat imagery of Pakistan is the detection of a new fault system which is now named the Quetta-Mustung-Surab fault system. This fault system is the youngest in the region and appears to be the result of differential movements along the Ornach-Nal and Chaman-Nushki fault systems. The trace has been delineated from the coastal range near the Hingol River north to a locale northeast of Quetta, a distance of more than 580 km. The fault trace trends north-south to a locality northwest of Surab. At a location 27 km northeast of Surab, branches trending northeast have developed. These branches become parallel with each other in the north. The traces of these faults are distinct in hard rocks. In sub-Recent and Recent alluvium, they appear to be faint lineations. Field checks have not yet been made to prove whether these are active faults. However, the seismic record (Farah, 1976) over the past 70 years shows that most of the seismic activity is associated with these faults. Most earthquakes of magnitude 6 to 7.7 on the Richter scale having focal depths from 0.50 km, and a few having focal depths from 51-100 km have been recorded from this region.

The Chaman-Nushki and the Ornach-Nal faults have been inferred to be the remnants of a boundary transform left-lateral fault which existed prior to the collision of the Indo-Pak plate with Asia. The time of collision has been considered (Powell and Conaghan, 1973, 1975; Stoneley, 1974; Molnar and Topponniar, 1975; Wensink, 1975) to be Eocene. After the collision, consumption of the Indo-Pak plate produced a crustal shortening of 1500 km. (Molnar and Topponniar, 1975); (Powell and Conaghan, 1973, 1975). Due to crustal shortening following the collision, the whole of the Indo-Pak continent must have moved about 1500 km toward the north. It is concluded that, after collision, a movement of this order should have occurred along the boundary transform fault. Several thousand feet of stratigraphic displacement has been reported by Hunting Survey Corporation (1960).

Wensink's (1975) findings based on magnetic anomalies discovered by Heirtzler (et al 1968), McKenzie and Sclater (1971), Laughton (et al 1973), and Sclater and Disher (1974), indicate that after collision of the Indo-Pak plate with Eurasia, during the period from 55 my to 35 my, there was no spreading along the Carlsberg Ridge. The northwest-southeast striking segments of the mid-Indian Ridge began forming 35 m.y. ago. The rise of these two ridges has not been equal. From the record of magnetic anomalies for the last 0-10 m.y., a rise rate of 1.1 cm/year per flank is calculated for the mid-Indian Ridge and 0-6 cm/year for the Carlsberg Ridge. Over the last 10 m.y., the addition of sea floor in the Arabian sea has been less by 0.5 cm/year per flank as compared with the increase of sea floor of the Indian Ocean. This resulted in the development of counter-clockwise rotational forces in the Indo-Pak plate. The effect of resultant counter-clockwise rotational forces accompanied by the northwest drift of the continent was the disruption of the Chaman-Nushki-Ornach-Nal fault, offsetting the southern segment towards the east. This process could safely be predicted to have started about 10 m.y. ago. After the offset of the Ornach-Nal fault towards the east, the tectonic activity in the north remained with the Chaman-Nushki fault. The tectonic activity in the south remained with the offset remnant Ornach-Nal fault.

New younger faults named the Quetta-Mustung-Surab fault system developed between the Chaman-Nushki and the Ornach-Nal faults to accommodate the tensional and compressional stress being caused by rotational and drifting forces. The new fault system follows a north-south trend from the coastal range to 27 km north west of Surab. At this location several branches facing northeast have developed. These branches of the fault become parallel in the northwest and follow the Quetta syntaxis (HTSC, 1960). The tectonic stresses accumulating in the Ornach-Nal fault and Chaman-Nushki fault are released through these younger faults.

The seismic record over the last 70 years indicates that most of the earthquakes of magnitude 6 to 7.7 on Richter scale, with focal depths from 1-5 km are associated with these younger faults. A few earthquakes had focal depths of 51-100 km. This indicates that tectonic activities along all three faults are still at work and the stresses accumulating could be released through any segment at any time.

Igneous geology studies

Landsat data for two sites, namely the Lasbela-Khuzdar and the Chaman areas, was interpreted to extract the information on igneous geology.

The igneous complex in the Lasbela-Khuzdar area consists of ultramafic basalt, agglomerate, gabbro, and lava flows, interlayered with sedimentary rocks. When studied visually the spectral reflectance levels of these rocks on Landsat images do not offer much density contrast. In bands 6 and 7, all these rocks have dark tones. In band 4 they seem to reflect more energy, as they have lighter tones as compared with bands 6 and 7. In band 5, there is some difference in reflectance levels between ultramafic and other mafic rocks. On the basis of reflectance properties and resolution on the ground three mapable divisions were made (fig. 14). These are (a) ultramafic complex (consisting of discontinuous peridotite bodies, highly serpentinized, with more than 85 percent olivine with accessory chromite, rarely showing primary layering); (b) mafic complex (consisting of basalt interlayered with agglomerate and sill-like bodies of gabbro); and (c) volcanic (consisting of basaltic lava with well-developed pillow structure interlayered with sedimentary rocks)(fig. 14).

One oval-shaped feature which appeared to be an intrusive body having a sharp contact with surrounding rocks was also picked up. The drainage pattern within this body did not look different in imagery from that of the surrounding area; however, the image tone of this body differed from that of other rocks because of its comparatively lesser reflectance. Field checks indicated that this feature is a porphyritic basalt plug, darker in color than surrounding basaltic rocks, and has discordant contact. Under thin section it was found to contain 40 percent groundmass of small laths of feldspar, about 30 percent small grains of a ferromagnesium mineral altered to chlorite, giving a yellow tint to the groundmass, and 20 percent opaque grains of disseminated magnetite partially altered to hematite. Pyroxene phenocrysts are altered along their borders to chlorite. Some phenocrysts which have been completely replaced by calcite resemble feldspar crystals in form. The alteration is so complete that it is difficult to identify the nature of the feldspar. The immediate detection of this body on the imagery could be attributed to its discordant contact with surrounding rocks and to its having a darker tone due to the presence of a higher percentage of disseminated iron and of phenocrysts of ferromagnesian minerals.

From the pattern of distribution of ultramafic and mafic rocks on the map compiled from Landsat imagery (fig. 14), it is evident that serpentinized dunite and peridotite are dominant in the northern area, gabbroic bodies are dominant in the central part and basaltic pillow lavas with sedimentary layers constitute the southern part. It can, therefore, be inferred that the Lasbela-Khuzdar igneous complex is part of the mantle which has been emplaced tectonically. The northern part represents the lower part of an ophiolite sequence, the central part the middle, and the southern part, the upper parts. The reflectance registered by granodiorite, diorite, and quartz monzonite is also similar in different bands.

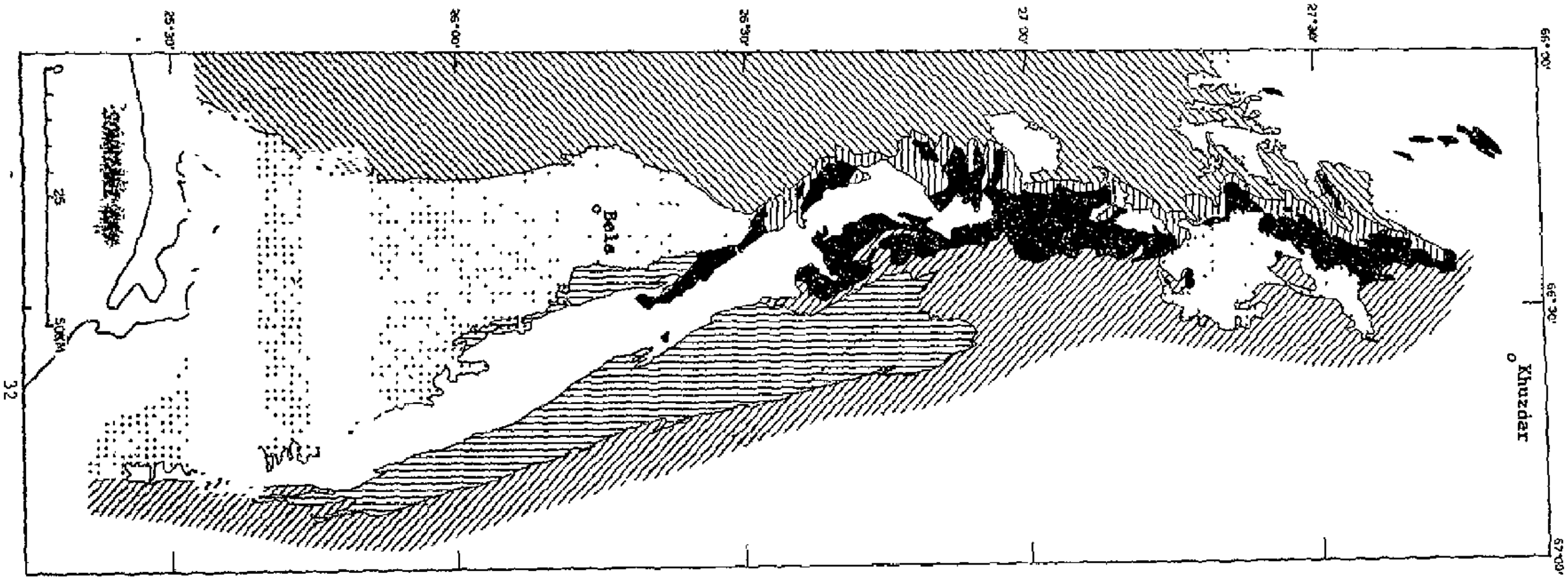

Figure 14. Map showing ultramafic and mafic complexes of part of the Lasbela and Khuzdar District, Pakistan.

EXPLANATION

Subrecent–Recent

Recent and Sub Recent. Sand, silt and gravel loose to semi consolidated or consolidated

OLIGOCENE - MIOCENE

Turbat and Hinglaj Group. Mainly sandstone with subordinate clayey shale and shaly limestone. The sandstone is gray to pale yellowish brown and weathers earthy-brown, dark yellow-brown. It is salt-and-pepper protoquartzite, soft and crumbly. Beds are well laminated to massive. The clayey shale, mudstone, and siltstone are sandy and soft, thin bedded, and at places gypsiferous.

Nal Limestone. Predominant limestone with subordinate sandstone, shale, minor conglomerate. The limestone is light gray on fresh surface and weathers yellow brown, dark brown, rusty brown, pinkish buff and light gray. It is thin to thick bedded and contains abundant fossils. The sandstone is green gray to pale yellowish brown and weathers earth brown, dark yellow brown, rusty and maroon. It is medium bedded, commonly micaceous, poorly sorted and has salt-and-pepper texture. Well-cemented and well-sorted varities are also present in minor amounts. The shale is soft, silty, clayey, or sandy and weathers earthy brown or green-gray. Lateritic red and earthy yellow, earthy shale is locally common. The conglomerate contains angular to well-rounded pebbles of igneous rocks that include serpentine and diorite and sedimentary rocks that include chert, gray limestone, and sandstone.

CRETACEOUS - PALEOCENE

Bela Volcanics. Lava interlayered with sedimentary rocks. Lava is basaltic with well-developed pillow structure, grayish green, olive, or greenish gray cryptocrystalline. Sedimentary rocks include limestone and shale. Limestone is cream, light green; weathers to yellowish brown; thin to medium bedded. Shale is green, buff, orange, blue gray, ferruginous brown, or black.

Bela Mafic complex. Basalt interlayered with agglomerate and sill-like bodies of gabbro. Basalt is dark grayish green, olive greenish gray, or dark gray on fresh surface and rusty brown or greenish gray on weathered surface; cryptocrystalline with feldspar laths and some olivine/pyroxene crystals. Agglomerate consists of subangular to subrounded fragments of porphyritic volcanic rock in a basaltic matrix. Gabbro is in the form of sill-like bodies. It is equigranular, holocrystalline, medium to coarse-grained; felsic and mafic ratios are: 30:60 to 60:30. Includes Porali Ultramafic complex.

CRETACEOUS

Parh Group. Shale, marl and limestone. Shale is gray, light green, olive brown, maroon and black on fresh surface and weathers to brown shades of these colors. It is calcareous, hard, flaky, or earthy. Contains small pellets or nodules of glauconite. Marl is yellow, red, or green; its weathered surface is characteristically nodular. Limestone is pure white, light gray, pink, green, and red. It is typically porcellaneous or sublithographic and breaks with subconchoidal fracture. The beds are characteristically regular, smooth faced, and tabular, ranging from 4 inches to 2 feet in thickness.

JURASSIC

Winder Group. Limestone with subordinate interbedded shale and few sandstone beds. Limestone is dark gray to black on fresh surface, weathers to light brown and blue gray, hard, compact; beds variable in thickness from few inches to few feet. Shale is light earthy brown, ferruginous brown, earthy blue gray, gray, and black; weathers to light brown, blue gray, and rusty brown; hard, splintery and calcareous; sandstone is light brown, reddish brown, or white; weathers to dirty white, pink or cream or light rusty brown; very hard and compact beds range in thickness from 2 to 6 feet.

The igneous complex of the Chaman area consists of rocks of the Sinjarani Volcanic Group and the Chagai intrusions (figs. 15, 16) exposed on the western side of the Chaman-Nushki transform, left-lateral fault. The rocks of the Sinjarani Volcanic Group consist of agglomerate, andesitic tuff, andesite, and porphyritic andesite. The rocks of the Chagai intrusions consist of diorite, granodiorite, quartz monzonite, and granite.

Among these rocks no photo-reflectance properties permitting differentiation of agglomerate, andesitic tuff, andesite, and porphyritic andesite were visually recognizable.

The reflectances registered by granodiorite, diorite, and quartz monzonite are also similar in the different bands.

Only three divisions which were possible visually have been made. These are (i) granite having a lighter tone; (ii) granodiorite; diorite, and quartz monzonite which have medium-gray tone; and (iii) agglomerate, andesitic tuff, andesite and porphyritic andesite having darker tone than (i) and (ii).

Significant results

The results achieved are summarized below:

1. An extension of the trace of the Chaman-Nushki capable fault was detected and delineated for 42 km.

2. An extension of the trace of the Ornach-Nal capable fault was detected and delineated for 170 km.

3. Two structural intersections responsible for restricted movements in particular segments of the Chaman-Nushki fault were detected and interpreted.

4. A new capable fault named the Quetta-Mustung-Surab fault system was detected. Its trace was delineated for 580 km. The new fault system is the youngest in the region.

5. The igneous complex of the Lasbela area was interpreted and differentiation was made between ultramafic complex, mafic complex, and basaltic lava flows.

6. One oblong feature was detected which has been interpreted as a porphyritic basalt plug.

7. Sedimentary rocks and the igneous complex of the Chaman area were interpreted. Sedimentary rocks were separated from igneous rocks. Among the igneous rocks, volcanic rocks were separated from intrusive rocks. Three broad subdivisions were made among the intrusive rocks.

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Figure 15. Landsat image of the Quetta area, Pakistan.

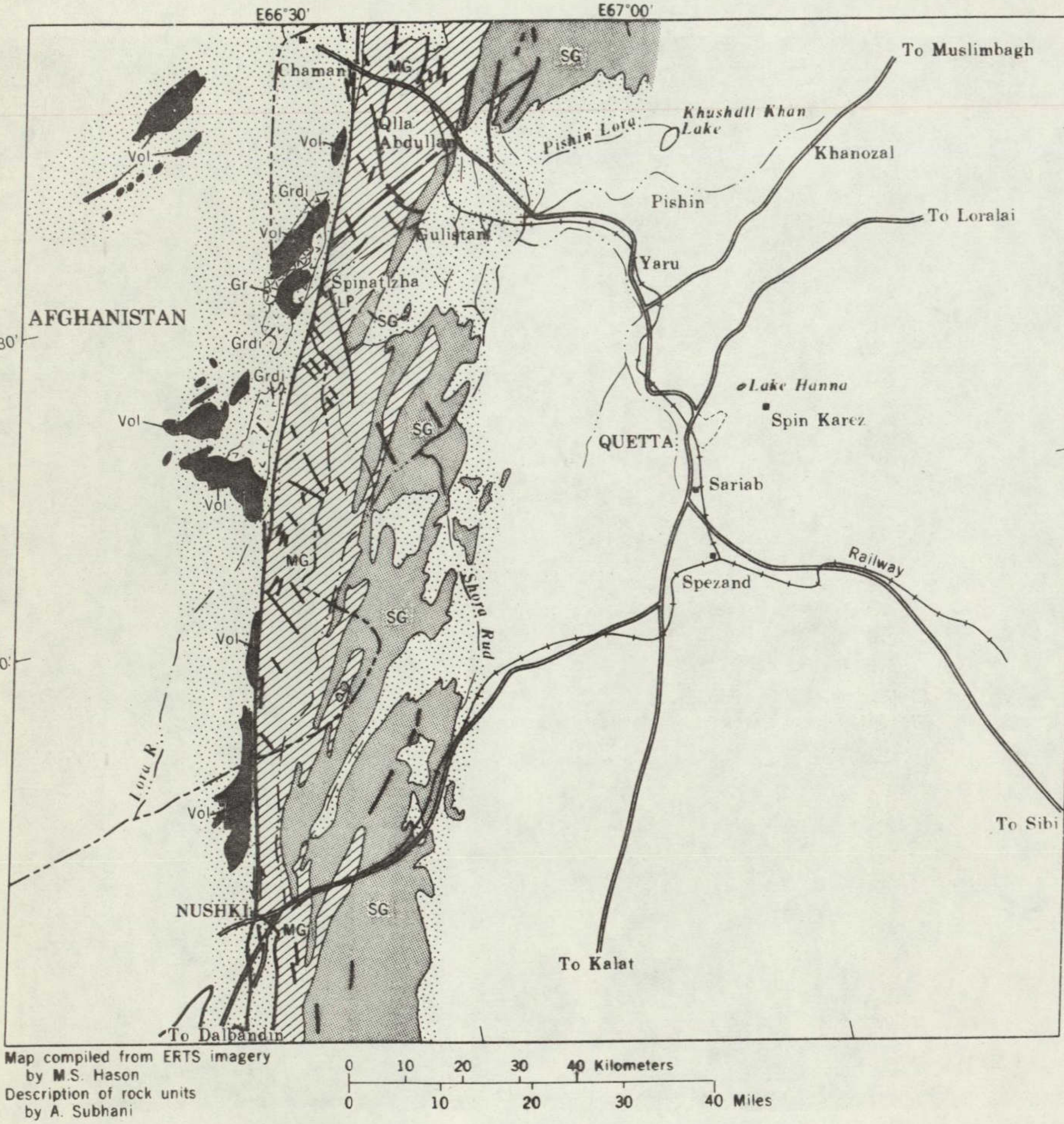

Figure 16. Map showing geology along the Chaman-Nushti fault.

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Recommendations

There is no doubt about the usefulness of Landsat data as it registers the spectral appearance of the elements, which are directly or indirectly helpful in conducting regional studies of a multi-disciplinary nature. It is felt that ground resolution should be improved to 20 meters and the images should be obtained with 60 percent overlap. The addition of a higher wave length band, namely thermal infrared, may be still more useful for detailed studies. It is, therefore, felt necessary that Pakistan be placed on the list of "Data Users" of NASA. It is hoped that the data which will be collected by future satellites, namely "Landsat C" and Stereosat, having improved ground resolution, spectral signature in thermal band, and also with stereoscopic effect may be supplied to Pakistan.

Opportunity may also be provided to study the degree of details registered in RBV images.

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INVESTIGATIONS IN TURKEY BY THE MINERAL RESEARCH AND EXPLORATION INSTITUTE OF TURKEY

Abstract

This project was undertaken within the framework of a CENTO Landsat-2 experiment program in cooperation with the US National Aeronautics and Space Administration. Landsat images of two areas in western Turkey were analysed to determine their applicability for mapping of the igneous and volcanic rocks and the tectonic features of the quite unstable North Anatolian fault zone.

The result of the studies of the Landsat images showed that they gave useful information on global tectonic problems, but that they were not very useful for detailed geological studies, especially in the regions with vegetative cover.

In addition, this project was helpful to educate a group of experts in the use of the Landsat data and their application to various geological problems.

Introduction

Geological remote-sensing techniques are employed to minimize costs and maximize results of ground-based geological investigations. Prediction of subsurface geological relationships from analysis of remotely sensed data is dependent upon the expertise of the data analyst who evaluates variations in electromagnetic energy reflected from the earth's surface and extrapolates to the subsurface using the surficial attributes and predictive, conceptual geologic models.

In order to test the applicability of remote-sensing methods and to gain experience in the analysis of remotely sensed data, a working group has been formed to study the recent tectonics and intrusive and volcanic rocks in selected regions of Turkey. This study has been conducted as a part of the CENTO Regional Landsat 2 experiment programme, in cooperation with NASA.

During the study, investigations were conducted in image interpretation by using magnifying glass, color additive viewer, and color composite prints from Landsat 2. During the image interpretation, a detailed ground truth program was arranged to check the validity of new findings.

Black and white prints of Landsat MSS image bands 4, 5, 6, and 7, at 1:1,000,000 and 1:500,000 scale were used. Imagery free of cloud cover and taken at different times of the year were available for only limited areas. Large 1:35,000 and larger scale aerial photographs were available for the study areas and they were used to great advantage. An old Delft scanning steoroscope was frequently used during the examination of the MSS images as well as the aerial photographs. Epicenter maps and publications about active faults of Turkey were referred to.

Studies of recent tectonics

Identification of lineaments was accomplished on each of the four bands by visual examination making use of the scanning stereoscope. For this purpose a pair of each band was prepared. Enlargements to 1:500,000 scale of some bands were made when necessary. Systematic studies were started with the location on the images of the previously known major active faults in order to establish criteria by which the active faults might be recognized. These efforts to find such criteria were not successful. It is believed that the small scale of the original data led to this result. Therefore, the task of finding criteria for the recognition of recency of faulting was abandoned and a new objective--to map the Quaternary and latest Tertiary faults, regardless of their date of activity was sought. The lineaments identified on the Landsat images were studied subsequently on the aerial photographs to determine the recency of the faulting. Photographs at scale 1:35,000 are generally suitable for this purpose. Ground truth studies were made in two areas: one in the western part of the North Anatolian fault zone to the south of Adapazari, and the other to the west of Lake Van, in an area where the eastern prolongation of the North Anatolian fault zone is assumed to be located.

Identification of major Quaternary faults is generally possible because of their prominent linear aspect; but there are no reliable criteria to identify an active fault.

In the period when the sun angle is lower, and when creeks are full and ground is wet, the lineaments become most readily detectable. Band 7 is the most suitable for this purpose in this period. On the contrary during the dry period, band 5 is generally more suitable than band 7 because of the heavy green vegetation covering dry valley flats.

Although the images taken in the wet period are useful for detecting lineaments, cloud cover, which is commonly seen in this period, has negative effects. Even 5 percent cloud coverage may mask a lineament if a critical area is covered by the cloud.

Three major lineaments which were suspected before are now identified on the MSS imagery (fig. 17). One which occurs near Malatya (fig. 18), a

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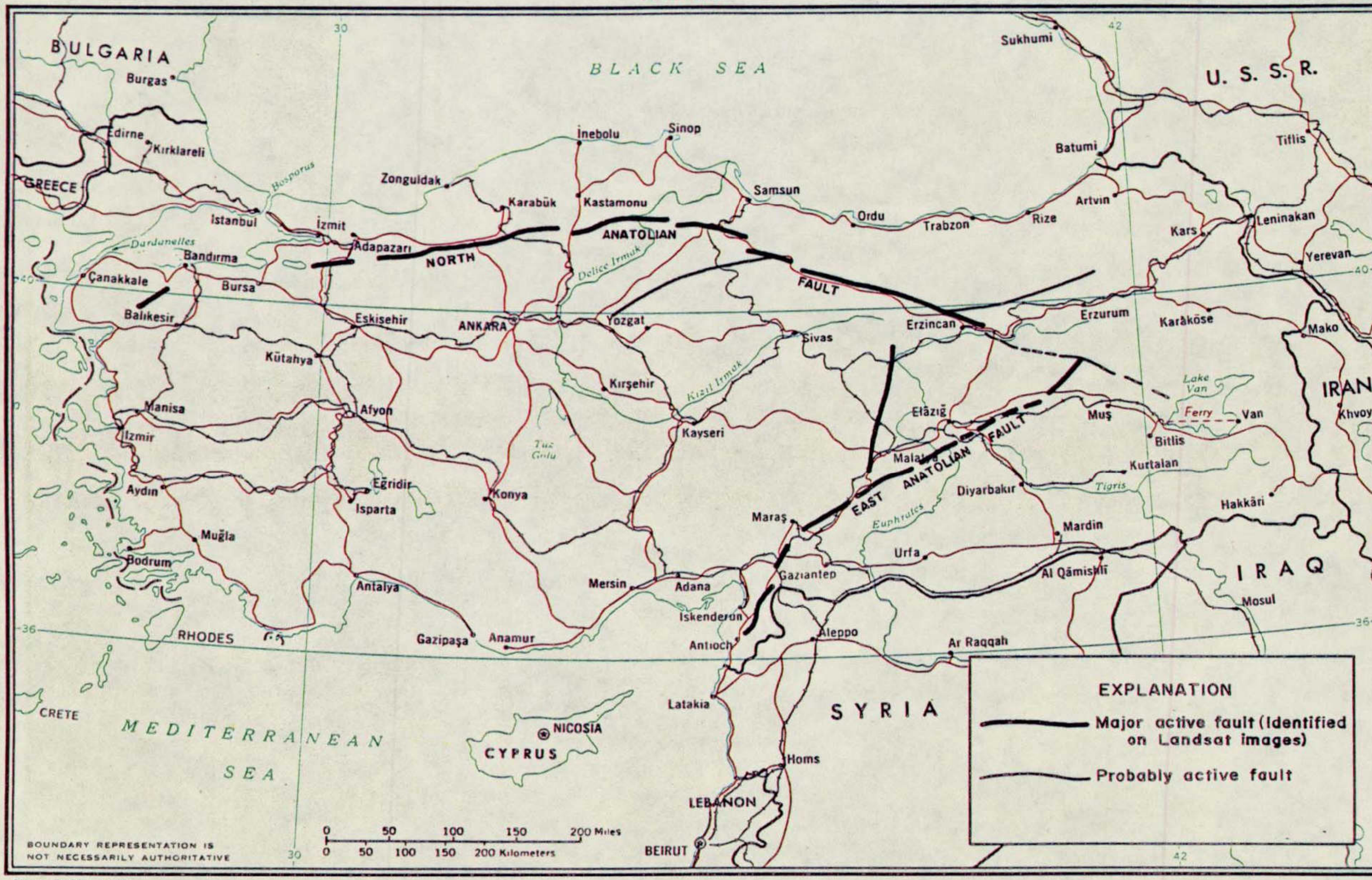

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Figure 17. Map showing major active fault trends of Turkey.

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crowded settlement area in eastern Turkey, was investigated and was recognized as an active fault. The other lineaments, each approximately 200 km long are still being investigated (fig. 19 and 20).

The fracture pattern, which is obtained by tracing the active faults and all the fault lineaments from the MSS imagery, can be very useful as an aid to understanding the stress systems and complex fracturing expected at the continental plate margins. As a followup to these studies undertaken to determine the usefulness of the Landsat images for identification of active faults and conditions of recent tectonism, researchers conducting seismotectonic studies became familiar with the imagery of Turkey and commenced using it in their larger research projects.

The original scale and resolving power of the Landsat imagery is not sufficient to determine whether fault lines are active; for that purpose the best scale appears to be 1:100,000. In general, Landsat observations at low sun angle are adequate for identifying the active fault lines, but if the scale is increased to 1:100,000, the present sun angle range for Turkey will become adequate.

Igneous and volcanic rock studies

Interpretation of Landsat imagery for the identification of igneous and volcanic rocks was concentrated in the areas indicated below; area 1 lies between the lat 36°30' and 38°00' N., and long 27°00' and 28°30' E., Area 2 lies between the lat 33° and 36°30' N., and long 29°30' and 33° E., Area 3 lies between lat 36°30' and 38° N., and long 32° and 34° E.

Analyses were carried out on black and white photographic prints of bands 4, 5, 6, and 7 and on color-composite prints. For the investigation of area 2, a color additive viewer was used to advantage in differentiating among the main rock types.

Area 1 is covered mainly by igneous and metamorphic rocks of the Menderes massif. Here it was possible to differentiate volcanic and igneous rocks of mafic composition from sedimentary and metamorphic rocks by tonal differences seen in the Landsat images.

Igneous rocks of silicic composition were differentiated by drainage patterns and the circular forms of the intrusions. Band 5 images were most suitable for identifying the volcanic rocks.

In the southern part of the Menderes massif, large areas are covered by ultrabasic rocks. In the imagery of this area, ultrabasic rocks could be distinguished from the surrounding sedimentary rocks by tonal differences and by the tectonic nature of the contacts. Other minor details of the ultrabasic rocks could not be differentiated.

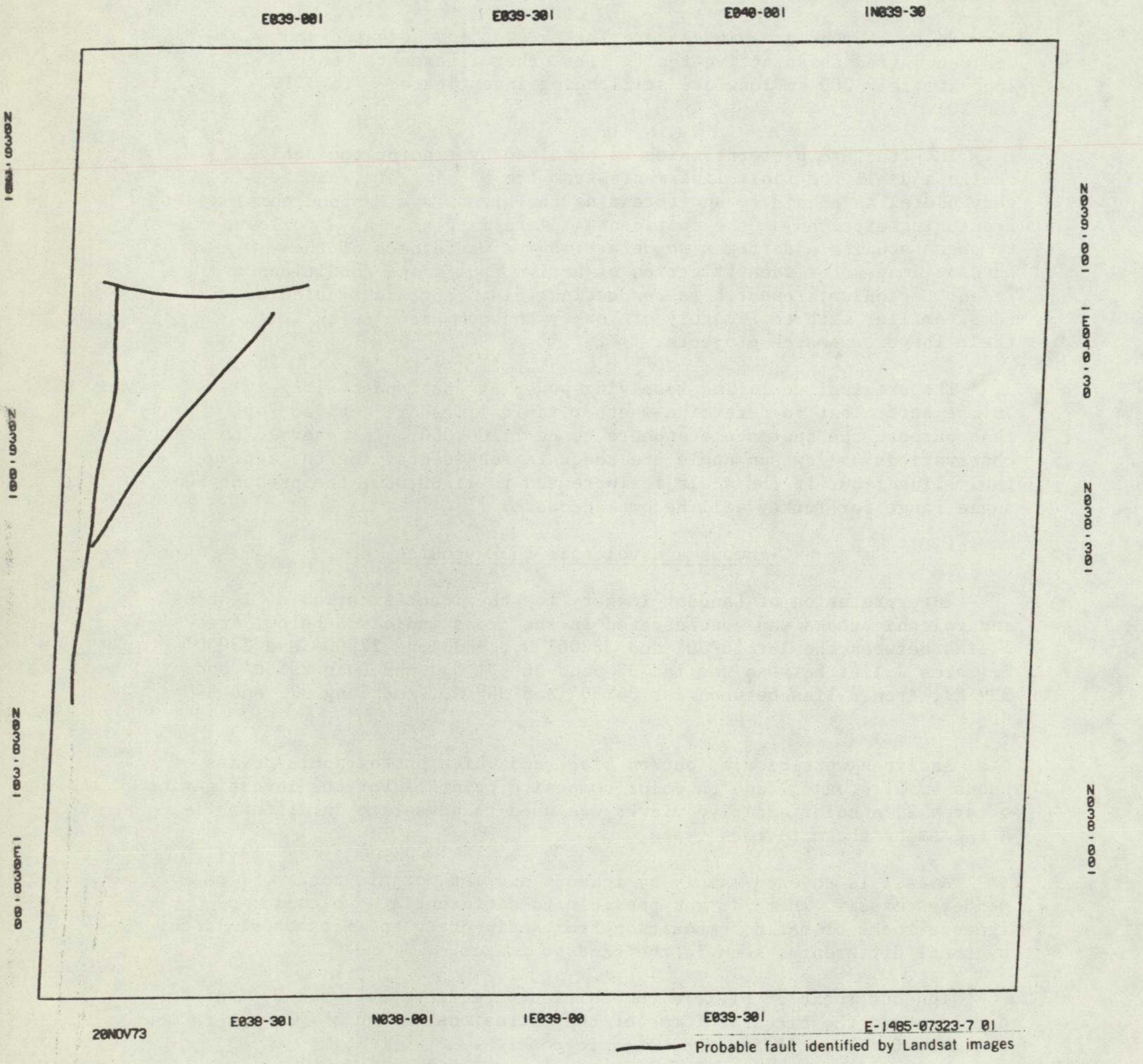

Figure 18. Overlay.

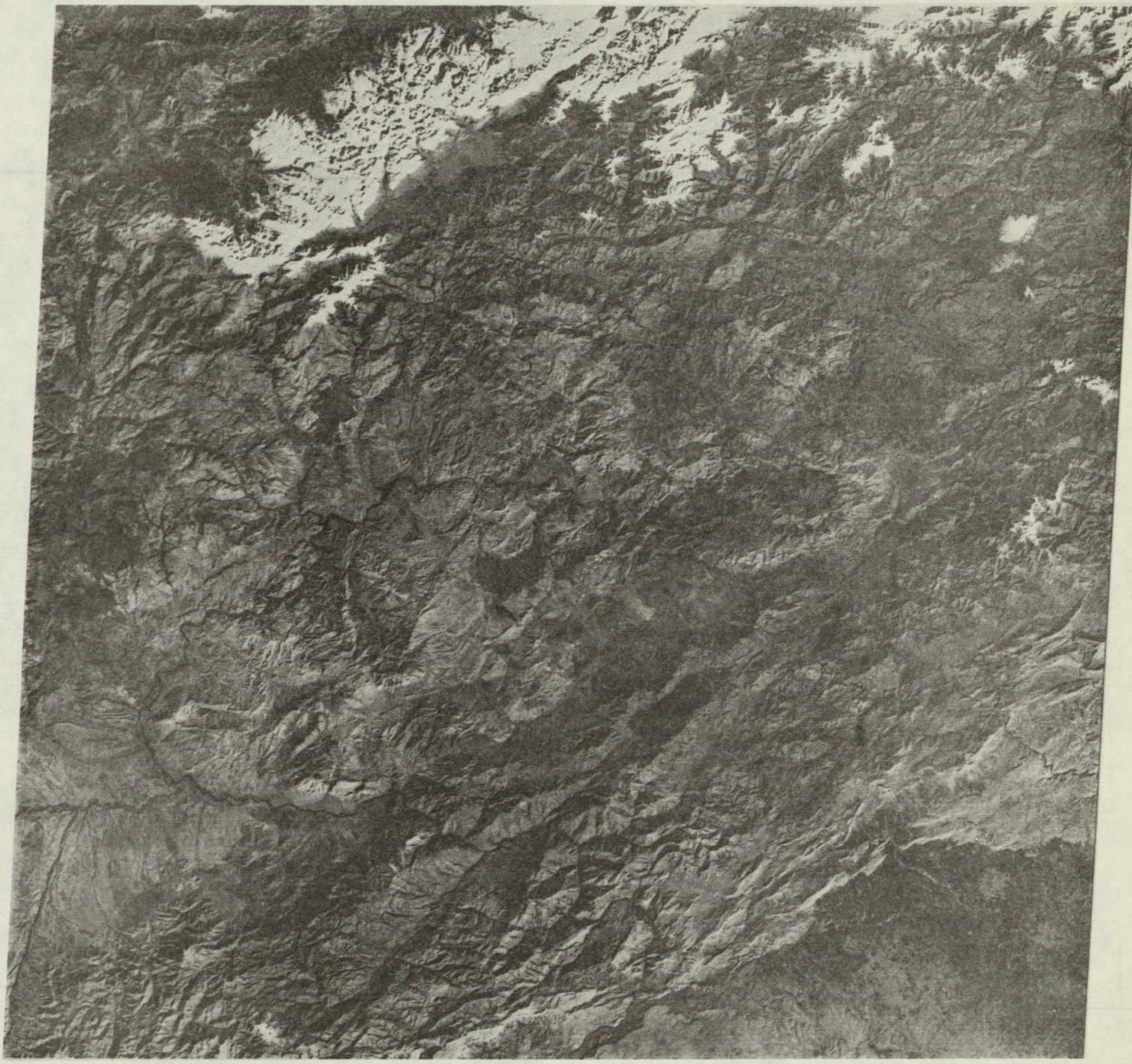

Figure 18. Landsat image showing traces of faults, probably active, in the Malatya region of eastern Turkey.

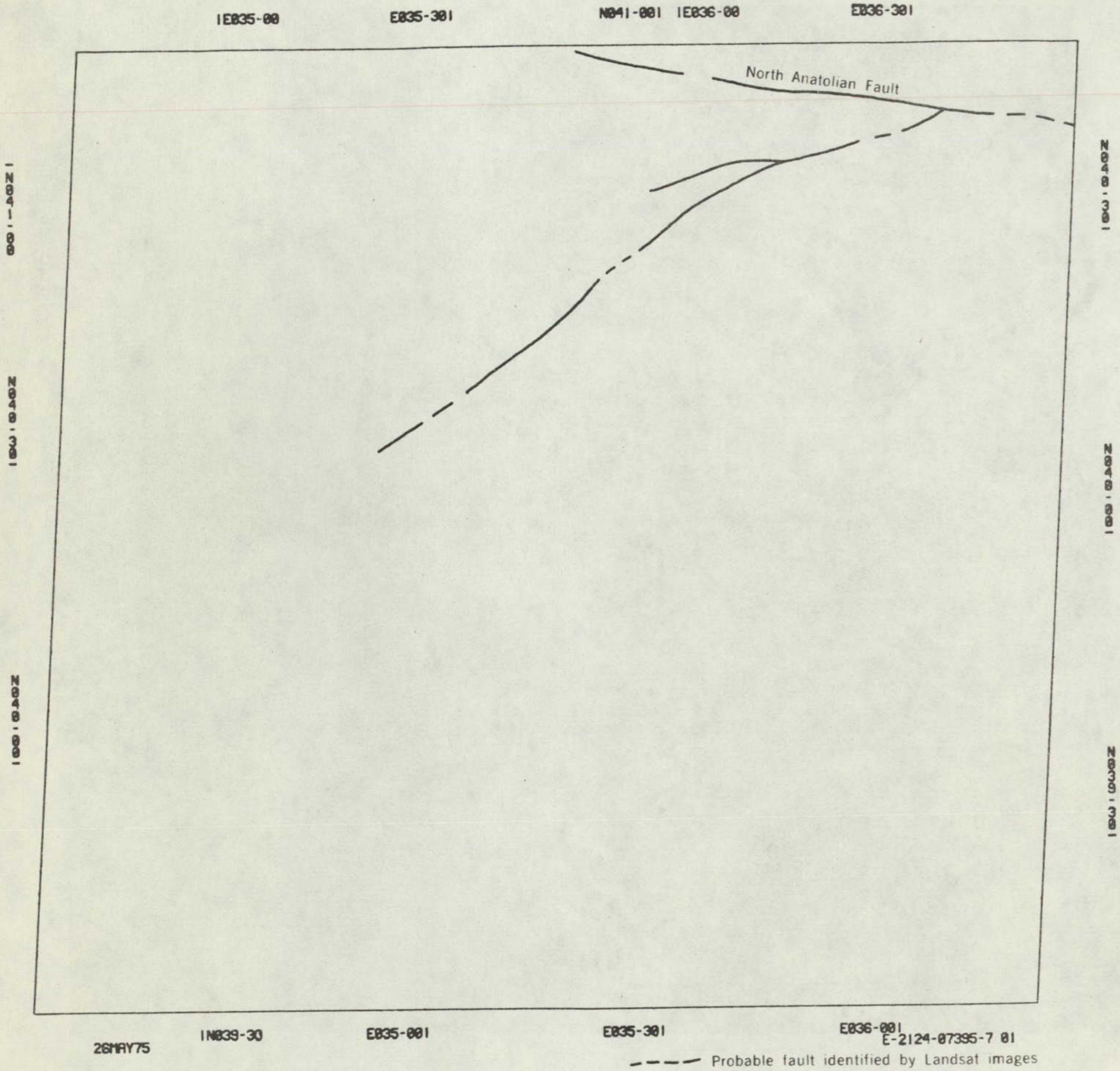

Figure 19. Overlay.

Figure 19. Traces of faults on Landsat image of the Zile region, north-central Turkey.

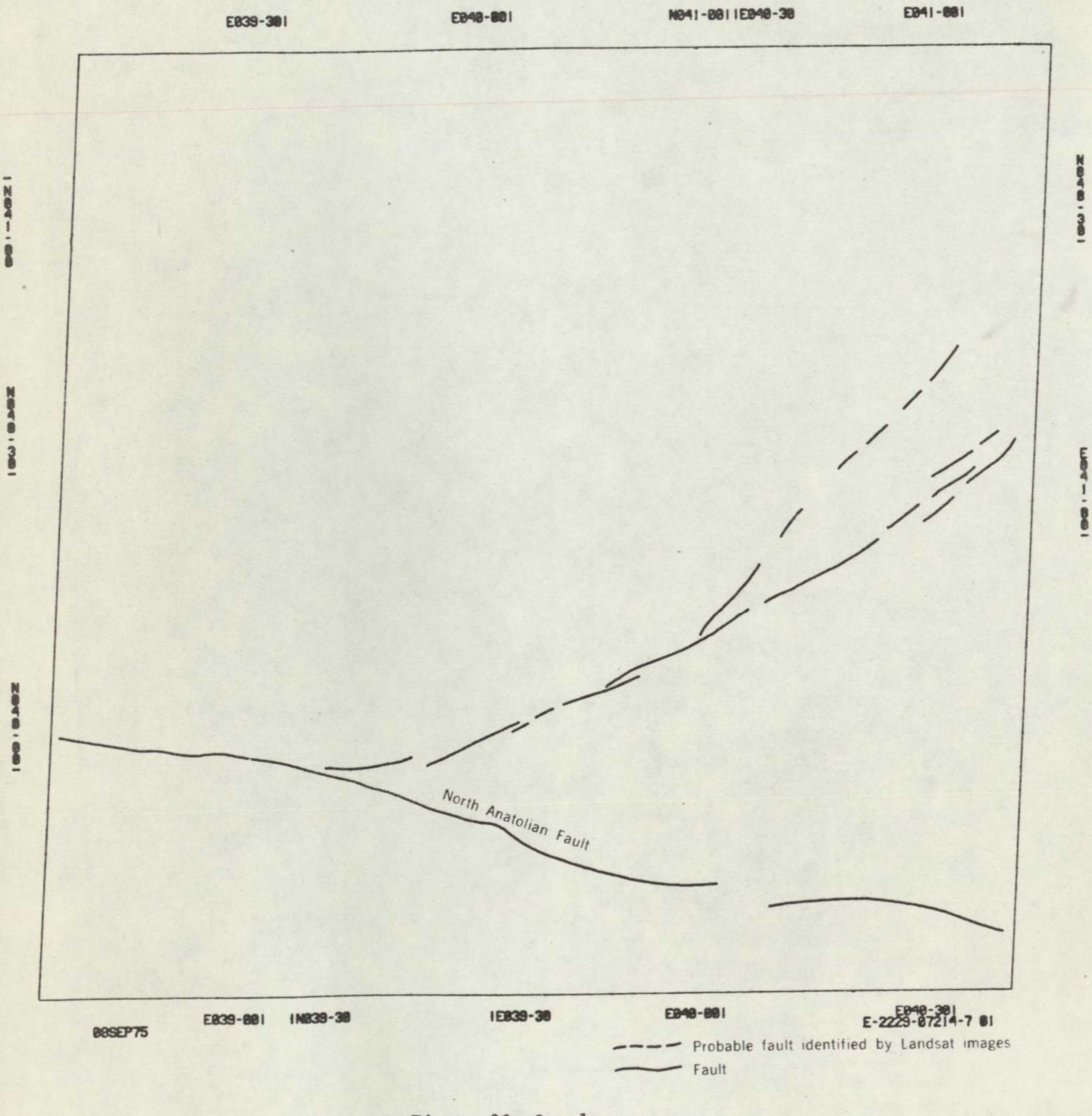

Figure 20. Overlay.

ORIGINAL PAGE IS
OF POOR QUALITY

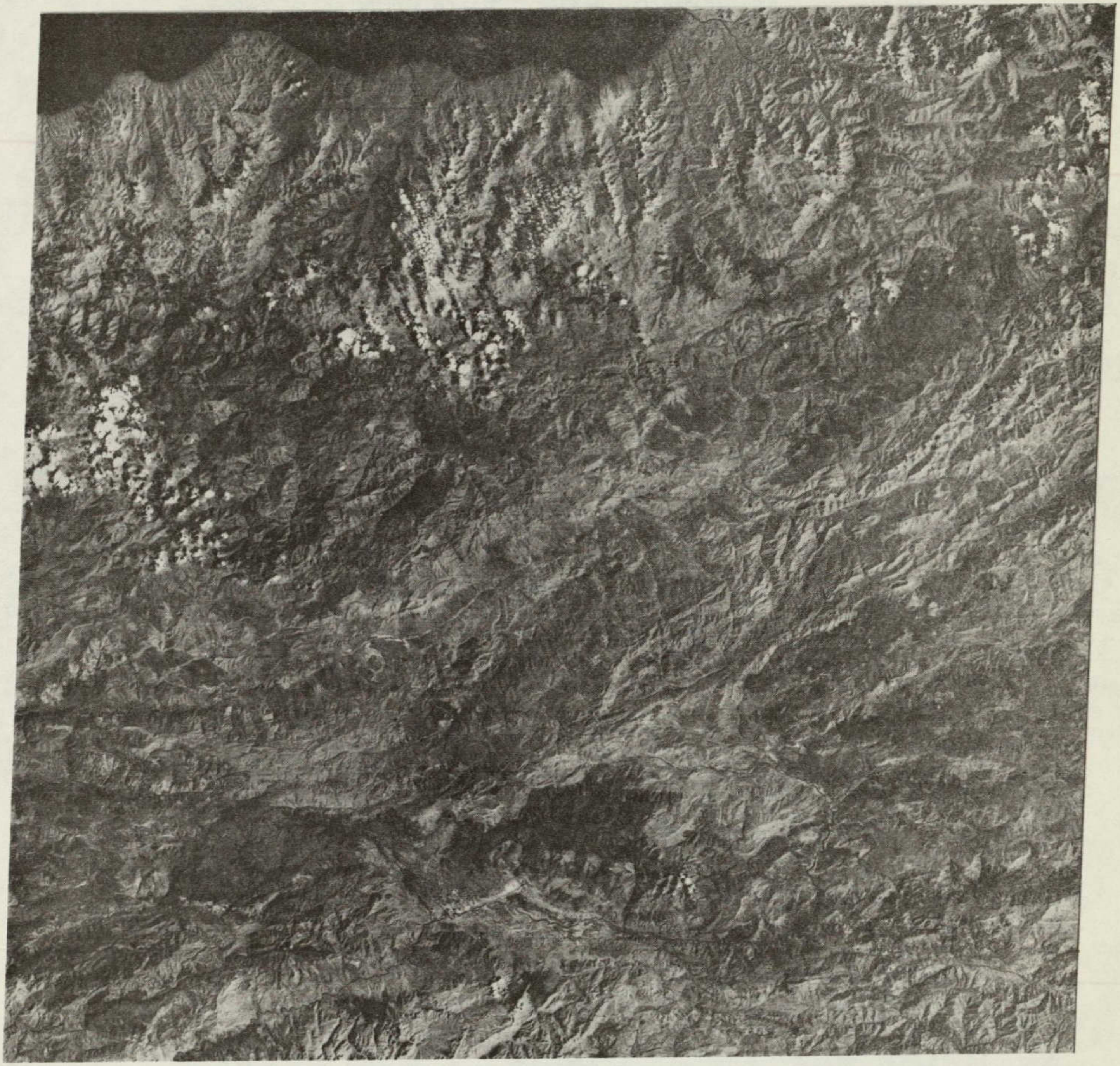

Figure 20. Traces of faults on Landsat image of the Erzincan region, eastern Turkey.

Area 2 lies to the north of the Bay of Antalya and the Lake district of Turkey. In this area it is observed that the general geology and tectonic grain are well reflected. There are three contrasting areas in the black and white photographs. It has been observed by comparing image tone with the known geology that ophiolites appear gray, andesites appear gray and display dendritic drainage patterns. Miocene sedimentary units appear dark gray and Tertiary and Mesozoic limestones appear white-gray. Delineation of these different rock types is comparatively easy because most contacts are tectonic, and faults and lineations are well reflected in this area.

With the aid of a color additive viewer, it was possible to differentiate among different rock types, but their delineation was restricted by the fact that the resolution was further reduced by the viewer.

Color composites were found to be superior to the black and white photographs for differentiating among the formations. Contacts of different units have been identified. These are Geyik dağı, Antalya, Bozkır, Alanya units, and travertines. In the east of the area 2, the following were identified:

(1) Quaternary: In color-composite prints of the Landsat images, and in composites in the color additive viewer employing different filters, the Quaternary is well differentiated. In the Quaternary, there are areas that show varied spectral reflectance that may be due to the presence of ground water.

(2) The Neogene is well identified to the north of Beyşehir Lake, and its contact with the Quaternary sedimentary rocks and with volcanics is well defined.

(3) Volcanic rocks: The volcanics of area 2 are very easy to differentiate from other rock types. Their contacts are very clearly defined. Furthermore, to the north of Suğla Lake, alteration areas in the volcanics can be recognized.

The results which were obtained from the studies of Landsat imagery are generalized below.

The differentiation of the volcanic and igneous rocks of mafic composition from sedimentary and metamorphic rocks has been achieved on the basis of tonal differences. However the differentiation of volcanic rocks of silicic composition has depended upon recognition of characteristic drainage patterns and circular form, in the absence of distinctive gray tones.

The images of band 5 were most suitable for identifying the volcanic rocks.

Contacts of the rock units drawn on the images were not very precise. On the basis of these images only small scale geological maps should be prepared.

Identification of igneous rocks of acidic composition has been possible only on the basis of differences in drainage patterns and the circular forms of igneous intrusions.

Although the identification of rock types in the areas studied and precise drawing of their boundaries has been difficult using Landsat imagery, lineaments of any origin have been well seen on it.

It has been found impossible to identify individual mineralized bodies with simple interpretation techniques, but, in general, Landsat imagery was found to be useful in determining interesting areas formerly overlooked in mineral exploration.